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THE USE OF A COMPUTER TO DESIGN SCHOOL BUS ROUTES.

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THIS PROJECT DEVELOPED A MANUAL TO BE USED BY TRANSPORTATION OFFICERS FOR COMPUTING SCHOOL BUS ROUTES. MATHEMATICAL TECHNIQUES WERE REVIEWED AND A COMPREHENSIVE STUDY MADE OF CRITERIA ELICITED FROM LITERATURE AND INTERVIEWS. QUESTIONNAIRES WERE MAILED TO SCHOOL AUTHORITIES TO RANK THE VARIOUS FACTORS INVOLVED. A COMPUTER PROGRAM WAS DEVELOPED FOR OPTIMAL ROUTING SERVICES. SOME OF THE GENERAL CONCLUSIONS REACHED WERE--(1) THE GREATER THE POPULATION DENSITY, THE MORE EFFICIENT THE PROGRAM UTILIZATION, (2) ROUTES CAN BE DESIGNED THAT ARE SHORTER, AND (3) BECAUSE OF VARYING CONDITIONS, NO TIME ESTIMATES WERE GIVEN. CHANGES ARE NOW IN PROGRESS ON THE SYMBOLIC PROGRAMING SYSTEM (SPS) FOR FURTHER EXTENSION OF EFFICIENT SERVICE. (RS)

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The Use of a Computer to Design School Bus Routes

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PREFACE

This final report is a manual to design school bus routes with the use of a computer. The rationale of the computer solution will be given as well as an extensive description with examples. In brief, the manual is intended to be used by school transportation officers to prepare data for a computing center and by computing center personnel to produce school bus routes.

Acknowledgment of my indebtedness to those who aided me on this project includes many names. My special gratitude is expressed to the staff of the Cooperative Research Program of the Office of Education and to the administrative officers of the University of Mississippi, who created the benign, non-directive environment in which I worked.

I want to express thanks to John Poole who spent a long, hot summer helping me work out the rationale of the computer solution. It is interesting to note that though the program has undergone many alterations, the basic concept remained unchanged. Also, gratitude is expressed to George Clement who assisted in translating our flow charts into computer language.

To Richard Ross and Tony Ross of the University of Mississippi Computing Center a debt is owed that I can scarcely hope to repay. They spent many hours making suggested revisions in the program. It was through their combined efforts that the program was completed.

Special recognition is given to John F. Murray, Schoharie Central Schools, Schoharie, New York, and to Robert A. Larsen, Robbinsdale Public School, Robbinsdale, Minnesota, who kindly sent me maps and data to use in the evaluation of the program.

If there are any errors, I alone am responsible. Although the manual has been checked diligently and photographs were made of much of our work in order to minimize mistakes, some errors will undoubtedly appear in this manual. Probably the first person who attempts an independent run of the program will find at least one error.

RAB

INTRODUCTION

The intent of this final report is the presentation of an algorithm that may be used to design school bus routes. The explanation is directed toward any school system that might wish to implement the program. Attempts will be made to point out the inherent limitations of the algorithm as well as some of the advantages. The general procedure is a heuristic program and no formal attempt will be made to analyze it from a mathematical (theoretical) point of view.

The discussion will take the following form. First a short review of related research will be given pertaining to both existing procedures of designing school bus routes and to the mathematical techniques that seem appropriate. Following will be an examination of the rationale used to develop the algorithm. The preparation of the data for the input phase of the program will be described in detail and will be followed by the algorithm in Symbolic Programming System (SPS IBM 1620) with 60 K Storage) with comments. The report will conclude with the presentation of the output of the program and a discussion of the results. The terms pick-up points, bus stops and points are used interchangeably, as are the words students and pupils.

REVIEW OF RELATED RESEARCH

A comprehensive review was made by Boyer (1961) of the techniques currently being used by school personnel relative to designed bus routes. During the last three years, no research was found to alter his conclusions that the designing of school bus routes is being done by relatively untrained personnel; and, because of the great task involved in designing even one bus system, alternate systems are rarely ever considered.

The mathematical framework that might ultimately provide the basis of designing the optimal school bus system for any given district appears still to be in the developmental stages. Several excellent related articles have appeared since the above review was made in 1961. Among these articles was one by Unger (1964) who noted that limitations of the purely mathematical solutions for testing pairs of directed line graphs for isomorphism, i. e. paths between points. He indicated that 40 years of running time on a very high speed computer might be required to compare two 15-mode graphs and concluded that the mere existence of an algorithm was of very little practical significance unless it is reasonably efficient.

The application of linear programming for optimizing the routing of shipments from warehouses has been reported by Kuehn and Hamburger (1962). They provided both a mathematical formulation and heuristic solutions. Their procedures were restricted to direct communication between customers rather than intervening stops as are required on school bus routes.

The work of Wright, Fletcher and Clarke (1964) concerning truck dispatching is more closely associated with the school bus routing problem than any other encountered. In fact, they report the same problems that we have been experiencing; for example, the task of developing a distance matrix is fraught with errors; excessive manual work is required, etc. The future efforts of Wright and others should be monitored closely by those interested in the routing problem.

In summary, the task involving the design of transportation systems in modern society is an astronomical one for both the computer and the manual worker.

Heuristic solutions appear to be the only ones that offer any assistance to those people who are responsible for efficient systems.

RATIONALE

Initially the school bus routing problem was conceived after reading a footnote to an article (Dantzig et al, 1954) on linear programming and extensions. At that time, and only at that time, the problem of using a modern high speed computer to design school bus routes was believed to be simple and straightforward; in other words, it was a nice, simple and compact problem.

At first a solution was attempted using a miniature school system having five given pick-up points and two buses. (At a later period a ten point school system was used). By manual means all possible bus routes were designed for the miniature school system, and the cost of each was recorded. Then I independently attempted to apply the linear programming and the simplex techniques to determine the optimal bus routes for these miniature systems. After many hours spent on many penciled papers, I went to local mathematicians for their assistance. Adding to my frustrated condition, no regional mathematician was located who had any practical experience with these modern techniques.

After an exchange of correspondence with Dr. Dantzig, CEIR, Arlington, Virginia, was visited in hopes that an optimal bus route could be described for a miniature system. It was there at CEIR that Winston Riley, III suggested that the concept of the use of linear programming might be discarded and, perhaps, a heuristic procedure would be fruitful.

In the months that followed, an attempt was made to analyze carefully the manual methods that were used to design school bus routes and then write a computer program to duplicate the hand computations, store the cost of each routing system and punch out the best solution. A manual method of designing routes was developed and was described by Boyer (1961) and later tested by Thompson (1963). Although the method was sequential, it did not lend itself to computer programming.

Concurrently with the development of a manual method, work continued from another point of view not based upon a human approach. This second method might be called a combinatorial programming technique which attempted to generate routes and to eliminate poor routes as quickly as possible by the use of time and distance restraints. A flow chart was prepared; and although much time and effort was expended, a working computer program was not written. On the other hand, this combinatorial technique did provide the bases for the rationale in the present solution described herein.

The combinatorial procedure mentioned above may be described as visualizing a group of bus drivers (K) sitting in a room each with a clip board containing a lined sheet of paper (internal counters). Each line is numbered and is referred to as a (LEVEL) on which the bus driver will write the pick-up point (I)--he will visit with the number of children (KIDS) he will pick up at that point. The order of points will determine his route. In front of all the drivers is a large black board containing the list (NX) of all pick-up points (I) and the number of students (KIDS) at each point. The director of the meeting (PROGRAM) begins by calling off the first point (I) on the black board (NX), and this point (I) is assigned to the first bus (K). The driver writes down the point (I) on the second line on his clip board (LEVEL) and records a 2 on the first line (LEVEL) to indicate that some point has been entered on the second line of his clip board. The driver now records the number of children (KIDS) at this pick-up point (I), adds the number to the number of pupils already on the bus (LOAD). If the number now on the bus (LOAD) is less than the bus's capacity (KAP), the driver is ready to consider another point. If the load is over the capacity (KAP), he checks to see if it is excessive, that is, greater than overloaded (NOVER). In the latter situation, the excess children (LO) are taken off the bus, the loaded bus goes to school; and the excess children wait until another bus is assigned to pick them up.

In cases where the bus is not loaded to capacity (KAP), the director reads the next point on the list (NX); and the driver of the first bus assigns the point (I) to the third line on his clip board and changes the number on the first line to 3, indicating a second pick up is now being considered, etc. After all the pick-up points had been assigned to some bus, the time (KOST) of each route would be stored and compared to (KOST) of subsequent routes. Only the best route was kept. It is to be noted that the order of the pick-up points in the list (NX) can be in any order; and it was anticipated that by generating different random order of listings, workable school bus systems could be generated.

In this method the number of possible generation would be greater than N! because discarded routes would not be kept. Since years would be required to generate and to evaluate all the bus routes for even a small school, it was hoped that by using the Monte Carlo technique, reasonably good solutions could be found. Flow charts were drawn up; but a satisfactory program was not written.

At this point, all previous work was put aside and a new combinatorial approach was formulated; namely (1) start at any given pick up point (I) in a school district, and draw a suggested route that would visit all points and would terminate at the school. (2) Partition the suggested route into segments each having a number of students (KIDS) equal to the capacity of a particular school bus (KAP). (3) After identification of each route, use a computer to generate all the possible routes of those points in each segment and to terminate at the school. (4) Compute the cost of each generated route (KOST), and identify the best route by inspection. (5) Compute by hand the total cost (KOST) of the best routes for that particular route system. (6) Introduce a new suggested route; and repeat the six steps listed above. Continue until several suggested routes have been partitioned, each segment generated and costs recorded.

The use of a human being to determine the starting point and to suggest a route as described in the paragraph above has two advantages:

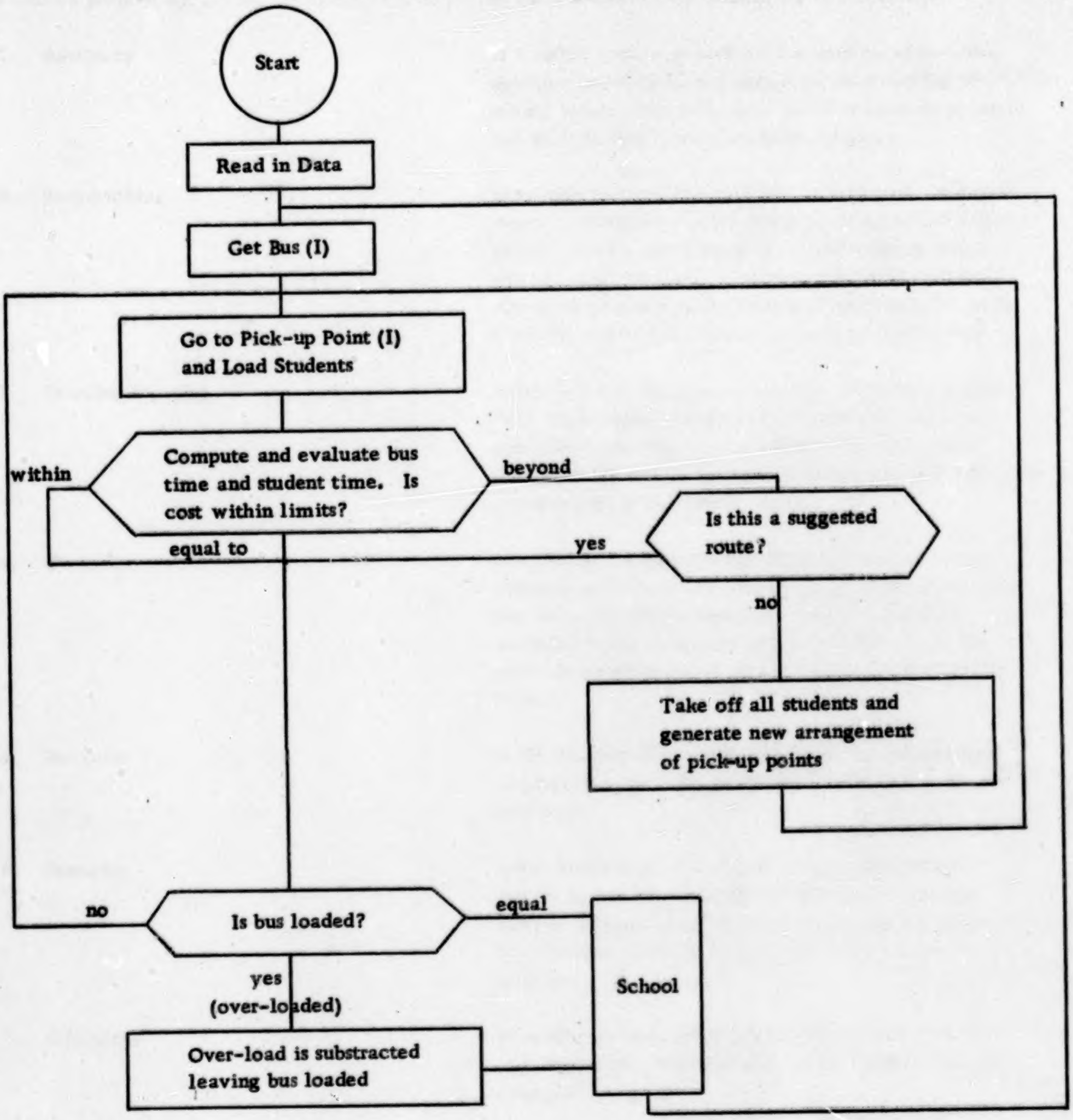
1. The computer program described in this report will generate by itself a route connecting all points and terminating at the school, but it would require an unknown number of computer days. By feeding

in a route that has been drawn by a person which does visit all points, the computer can partition this suggested route into individual bus routes in a matter of a few seconds.

2. The place to start the first bus route is a very significant item because all subsequent routes are dependent upon the first route, and the first route is dependent upon the first point. In the solution described in this report, since any point (except school) can be used as the starting point, several different types of starting points can be suggested, such as the most extreme point, nearest point, middle distance point, etc. Therefore, a range of starting points can be suggested. It is true that such a solution introduces bias and the computer could select starting points, but such would be too costly in regard to time.

On the following page is a simplified block diagram of the general approach used in the program.

Below is a simplified block diagram giving the general approach used in this project:


Start
Read in Data
Get Bus (I)
Go to Pick-up Point (I) and Load Students
within
Compute and evaluate bus time and student time. Is cost within limits?
beyond
equal to
yes
Is this a suggested route?
no
Take off all students and generate new arrangement of pick-up points
no
Is bus loaded?
equal
School
yes (over-loaded)
Over-load is substracted leaving bus loaded

Another problem encountered in the project was the criteria by which a school bus system may be evaluated. Many variables were considered; and only one, the cumulative time each student spends enroute to school, is suggested in this Final Report as the criterion that the transportation official should use to evaluate bus systems. This "total student time" is a very subtle value and is dependent upon many other variables as will be pointed out below. A description of all the variables that were considered is as follows:

1. Adequacy	is a rather elusive generalization used by writers who describe broad problems associated with routing of school buses. The term does not lend itself to numerical analysis and is not used in this study.
2. Backtracking	is related to "turn arounds" and refers to the condition where a partically loaded bus goes over the same road twice. Most experts agree that such sould be minimized. This variable is indirectly included in the computer program under "student time" because backtracking will tend to double the student time value.
3. Boarding location	refers to a child's crossing the road to board a school bus. Under ideal conditions all children would not cross the road; this is a condition to be minimized. This variable can be incorporated into the computer program as part of the LMAT matrix.
4. Bus miles	is a variable frequently mentioned by transportation officials as their major concern; i.e., how many miles the buses are driven each day. Bus miles can be included in the computer solution of the school bus problem by using miles instead of time in the MLINK matrix.
5. Bus time	is the number of minutes a bus is driven while transporting students. This variable is included in the present study.
6. Economy	refers to the unit cost of operating a transportation system and is usually reported in terms of costs per mile or number of miles buses are driven each day. No economy variable is included in the computer solution.
7. Efficiency	is another evasive criterion but usually refers to some monetary cost. This variable is not included in the computer program.
8. Grade level of children	being transported affects the rated capacities of school buses. In some areas a 54 passenger bus is permitted to transport 60 elementary children and 42 high school students. This variable can be incorporated in the computer solution because bus capacity can vary from bus to bus.

9. **Location of residence of driver**	is considered by some writers as a factor in planning bus routes. However, since the computer program attempts to transport all children in the minimum amount of time, the location of the residence of the driver is not considered in the present project.
10. **Location of garage**	is a variable that receives much consideration by writers advocating loop routes and other writers emphasizing maintenance. This variable is not used.
11. **Railroad crossings**	is a factor that receives much attention, but no research was found where the number of railroad crossings was minimized. This variable can be included in the computer program by exaggerating distances between pick up points in the MLINK matrix.
12. **Road conditions**	have been recognized by many writers as an important variable. In most cases only a report of the number of miles of paved, graveled, and dirt roads are given. The present computer program can incorporate road conditions in the MLINK matrix.
13. **Road gradient**	is a variable usually restricted to mountainous areas. The grade of the road can be incorporated in the computer solution in the MLINK matrix.
14. **Salary of driver**	is an economic variable, and is not included in the present solution.
15. **Safety**	is another generalized variable that is difficult to define in quantitative terms. Although many writers state that bus routes should be planned to insure the safety of the student, most all work in this area has been restricted to study of steel bodies, larger lights, greater vision and longer signal arms. Should safety be interpreted as minimizing the time children are enroute to school, the computer solution includes this variable.
16. **School starting time**	is a factor that must be included in all transportation plans. The present solution uses this variable.
17. **Size of buses**	relates to the different sizes of buses available to transport the children. The computer program can accept buses of varying capacities.
18. **Student miles**	is the total number of miles all students ride, _i. e._, if four students rode three miles, twelve is the number of student miles for this system. Although some writers infer that such a variable should be considered in designing bus routes, no case was found where the variable had been used. Student miles can be included in the computer solution by using distance units instead of time units.

19.	Student time	is the total number of minutes all students ride; *i. e.*, if six students spend eight minutes aboard a bus enroute to school, the student time would be forty-eight minutes. This variable is minimized in the computer solution.
20.	Turn arounds	is a variable closely related to "backtracking" and "safety," *i. e.*, if turning a bus around is considered to increase the probability of an accident. The number of turn arounds in a school system can be minimized by selecting routes with the least student time.

In summary, student time was judged to be the best criterion because it does include such variables as backtracking, safety and road conditions. If one assumes that safety can be measured by time, *i. e.* the safest route is one which is the shortest, then student time also includes a safety factor. You are to recall that dangerous traffic conditions and crossings can be included in the schema. Furthermore, the school bus routes are to be expressed in terms of student values rather than some external units.

PREPARATION OF DATA

There are two phases in the preparation of the data for use in the computer. In Phase 1 the school system is partitioned into individual bus routes by means of suggested routes. Phase 2 consisted of generating all the feasible routes for each partition or segment. After all routes have been generated, the print out is inspected to determine the best generated route for each partition or bus. After determining the cost for each suggested route, the best system is then determined.

General format for input data

All input data are punched in five digit fields beginning in column 1 and ending with column 80; *i. e.*, 1-5; 6-10; 11-15; ... 76-80. No field will contain any alphanumeric or special characters. No decimal point will be used.

PHASE 1

The INPUT data for Phase 1 consists of the following:

Matrix data

Suggested route

Header card for suggested route (Header Card Number 2)

List of buses available with the capacity of each

Header card for SPS School Bus Program (Header Card Number 1)

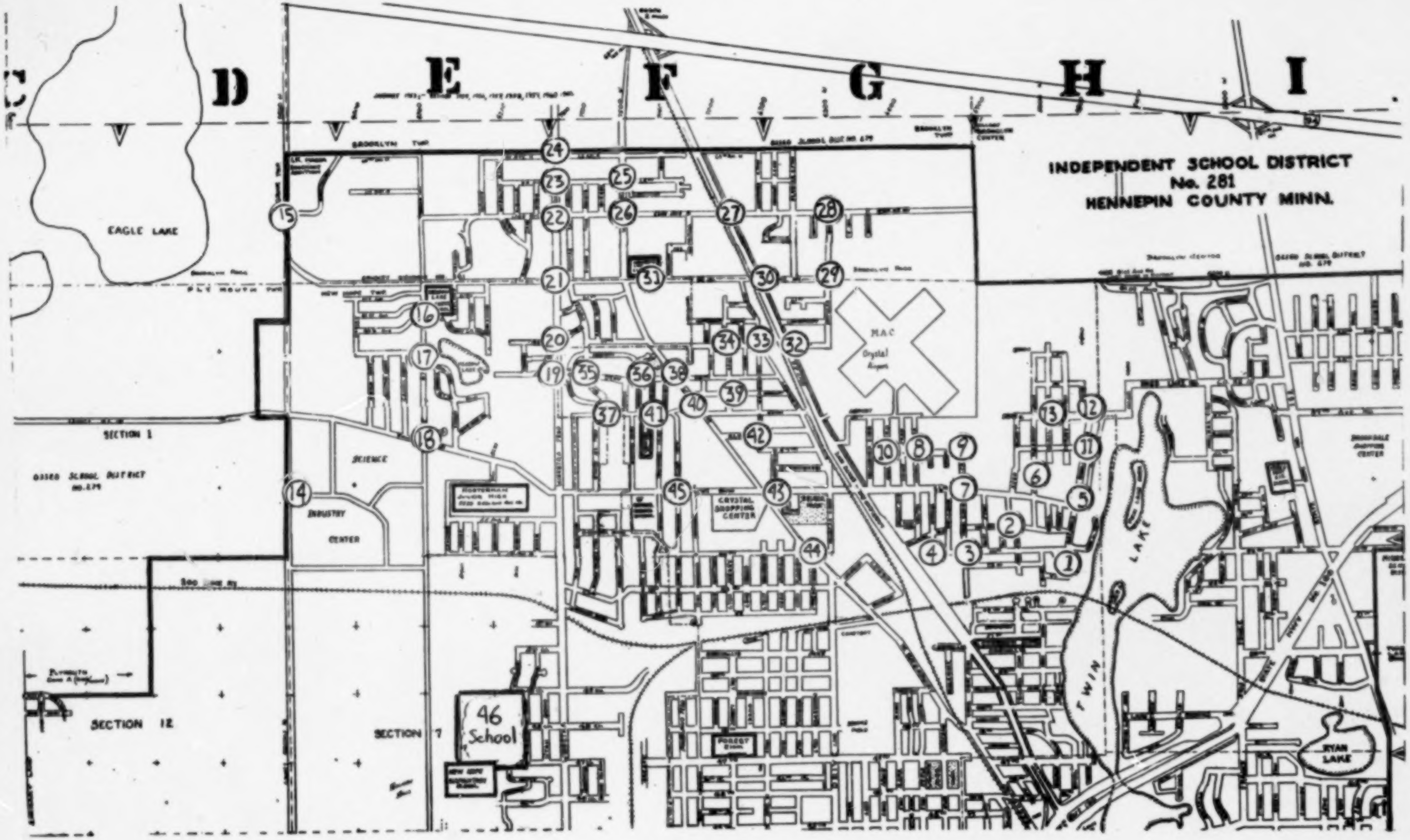
Matrix

The INPUT MATRIX is based upon the transportation map that is usually prepared in most school systems. The transportation map is to be made at the local school level and gives the location of each bus stop (identified by a number), location of the school (identified by a number), the number of children at each stop and the length of time required for a bus to travel between adjacent stops. Figure 1 gives a basic transportation map listing bus stops. After the transportation map has been prepared, the map is to be inspected for variables that are to receive special consideration such as dangerous intersections, one way streets, bridges with load limits, road gradients, etc. These variables have been discussed above.

Mention will be made here of a method that can be used to locate bus stops. The first school system for which we attempted to design school bus routes was the Schoharie School System, New York, which provided transportation maps giving only the residences of the children. In this situation one bus stop was established on each road segment and at an estimated centroidal point. In other words, a bus would be required to go along each road segment on which a child lived. This method is recommended for the preparation of data based on rural districts because if one had to consider every residence, the input matrix would become too large.

After the variables which are to receive special consideration are noted on the map, the INPUT MATRIX can be prepared. At this point many subjective decisions are introduced into the algorithm, some of which will be described in the following paragraphs.

Attention is now directed to Figure 2 which presents the road map for a section of the Robbinsdale School District, Robbinsdale, Minnesota. The decisions relating to Point 6 will be discussed. In all cases


INDEPENDENT SCHOOL DISTRICT
No. 281
HENNEPIN COUNTY MINN.
C
D
E
F
G
H
I
EAGLE LAKE
SECTION 1
OSSEO SCHOOL DISTRICT NO. 279
SECTION 12
SECTION 7
SCIENCE
INDUSTRY
CENTER
CRYSTAL SHOPPING CENTER
MAC Crystal Airport
TWIN LAKE
RYAN LAKE
46 School
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
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27
28
29
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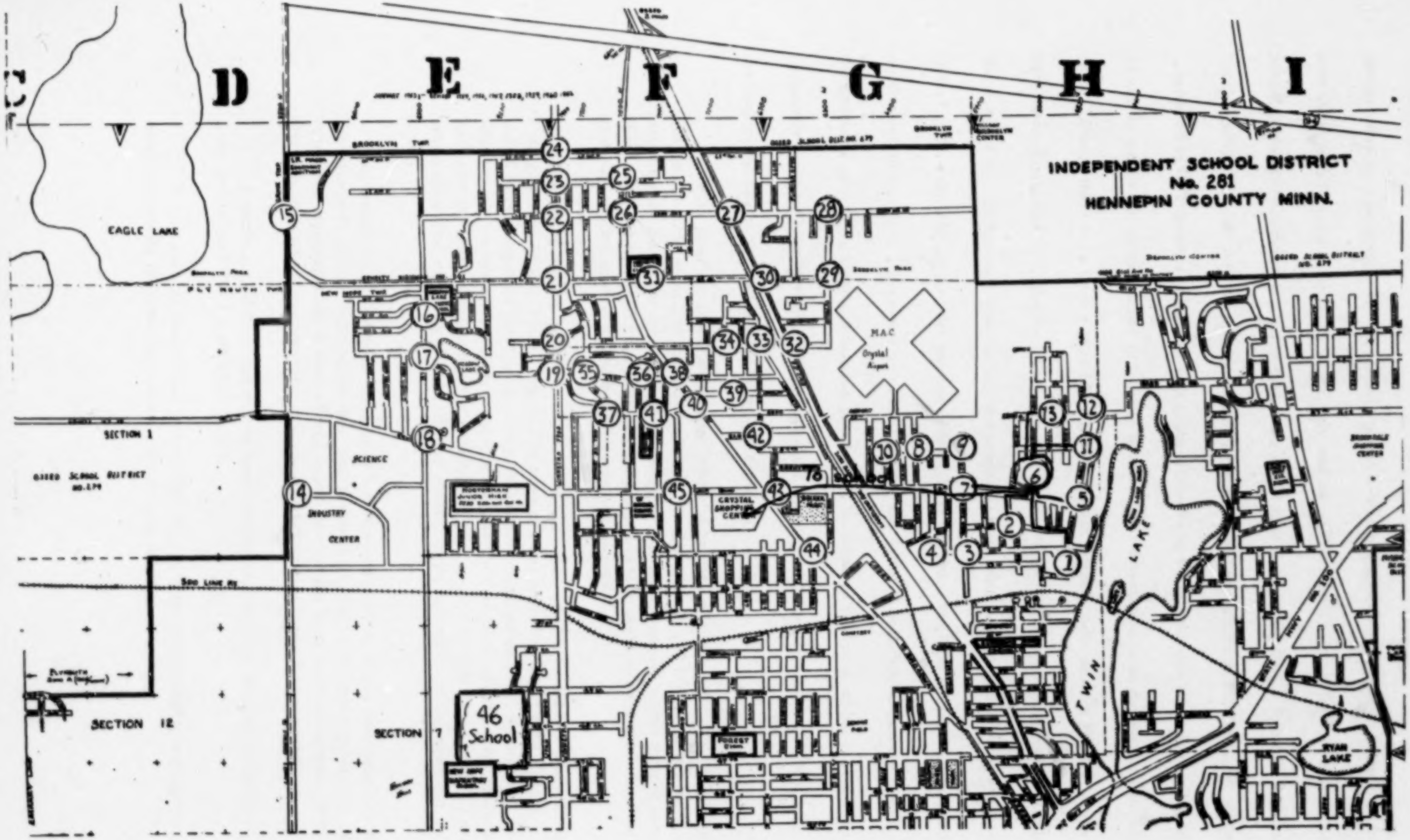
41
42
43
44
45

Figure 1. Map of Robbinsdale showing pick up points and school.


INDEPENDENT SCHOOL DISTRICT
No. 281
HENNEPIN COUNTY MINN.
C
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EAGLE LAKE
BROOKLYN TWP
PLYMOUTH TWP
SECTION 1
SECTION 7
SECTION 12
SCIENCE
INDUSTRY
CENTER
M.A.C.
Crystal Airport
CRYSTAL SHOPPING CENTER
TWIN LAKE
RYAN LAKE
SOO LINE RR
To school
46
School
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
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36
37
38
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40
41
42
43
44
45

Figure 2. Pick up points to be visited from point number 6.

the first step is to determine all the feasible points to which a school bus might go from Point 6. In this case these points would be 1, 2, 5, 7, 11, 13, and 46. (The school is identified as Point 46, and the school is always considered as a point that a bus might visit from each point). Point 12 is not included because a bus probably would pass either Point 11 or Point 13 to reach Point 12; therefore, Point 12 is not considered to be a feasible point. In a situation where Point 6 was on a one way street going south, Points 13 and 11 would not be considered as feasible because the bus would have to double back to reach either point. Should there have been a NO LEFT TURN situation immediately south of Point 6, Point 5 would have been eliminated as a feasible point. No recommendation is given as to how many feasible points there should be. In the work done so far, the range has been from two (in cases of one way streets) to twelve. However, the greater the number of feasible points there are, the longer the computer will take to reach a solution. Also, the greater number of points, the easier it is to draw suggested routes. In all cases the decisions relating to listing of feasible points must be made by the local school system. Some of the comments made by John Murray, Schoharie Central Schools, are most appropriate at this time, as he evaluates one of the computer solutions for his school district.

> With some modification solution #3 could be used in its entirety. Our difficulty in our remote rural areas lies in road conditions. In the summer and fall all of our roads indicated on our present or original map are passable. In the spring and winter months some of these roads are not freed from snow and maintained as to prevent washout from flooding so that they are not used as school bus routes for our operation.
>
> Some secondary bridges maintained by towns are avoided because of weakness for our sixty passenger buses. I have penciled in some of these areas on the solution #3 map. I should have designated these areas in my preliminary information that I submitted. As I was asked to submit current bus routes, I did not realize the computer would use all available routes on the map. In securing this information from central schools in the future, I would recommend that a map be marked to show roads that are not usable so the computer will use them.
>
> Routes one, two, three and four as indicated on solution #3 are very feasible; and I am extremely pleased with routes five, six, seven and eight. This area (routes five, six, seven and eight) contains a rural village about seven miles from the schoolhouse. With only slight modification, the computer solution in this particular area is very useful.
>
> Routes nine, fifteen and sixteen need greater modification because of impassable roads and bridges that I mentioned before.
>
> Routes eleven, twelve and thirteen are similar to our present ones; and again, with the modification the computer has shown, can be very useful.

> Further modification may be necessary from a safety standpoint in our particular district. We are inclined to pick up students living on our well traveled state highways on their respective sides of the roads rather than have the students cross in heavy traffic. Therefore, on our current map some of our buses are running over the same road areas twice. In some instances this can be accomplished with the computer solution also.[1]

The identification of the feasible points to which a bus may travel from a given point is the LMAT part to the INPUT MATRIX and these points are recorded on a work sheet as shown in Figure 3.

After determining these feasible points, the next task is to calculate the amount of time that will be required for the bus to travel between these points. For example, in Figure 2 the amount of time that is required to go from

	Estimates of Time Units
Point 6 to Point 1	3
Point 6 to Point 2	2
Point 6 to Point 5	2
Point 6 to Point 7	2
Point 6 to Point 11	2
Point 6 to Point 13	2
Point 6 to Point 46 (School)	20

These values must be provided by the local school personnel. Should a school district not be interested in time, miles can be used instead. However, since the computer program has been written to schedule buses to arrive at school by a certain time, the time unit of minutes is recommended. Again these values are entered on the work sheet as shown in Figure 3.

In cases where variables are to receive special consideration, the time required to go between points can be exaggerated and thus impose a type of penalty. Consider the points in Figure 2. Suppose 56th Street (the east-west street immediately south of Point 6) is a heavily traveled street and that the transportation officer would prefer not to make a left hand turn, but would if he had to. To reflect this attitude, travel from Point 6 to Point 5 would be considered as feasible; but the time to travel would be increased from 2

---

[1] Personal communication.

(NLAR) Level	Point 1		Point 2		Point 3		Point 4		Point 5		Point 6		Point 7	
	LMAT	MLINK	LMAT	MLINK	LMAT	MLINK	LMAT	MLINK	LMAT	MLINK	LMAT	MLINK	LMAT	MLINK
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	1	2	1	3	3	1	1	2	1	3	2	2
3	3	3	3	2	2	2	7	3	2	3	2	2	3	2
4	5	2	5	3	4	1	8	3	3	4	5	2	4	3
5	6	2	6	2	7	2	10	4	6	2	7	2	5	3
6	46	22	7	2	46	20	43	5	7	3	11	2	6	2
7			46	21			44	7	11	1	13	2	8	2
8							46	19	46	21	46	20	9	1
9													46	19
10														
11														
12														
13														
14														
15		22		21		20		19		21		20		19

Indicates 2 minutes travel time to go from Point #6 to Point #7

Time required to reach school (Point #46) From Point #6

List of all points that a bus may travel to from Point #4 time units to 3 time units or minutes, thereby lengthening the bus route and student time required for such a routing. Railroad crossings, bridges and other features can thus be included.

The time values of the INPUT MATRIX are called MLINK.

After the work sheet (Figure 3) has been completed, Table 1 can be prepared using the same data in practically the same format. Table 1 is a copy of the actual input data.

TABLE 1. LMAT AND MLINK MATRIX

NLAR	POINT	LMAT	MLINK
1	1		
2	1	2	2
3	1	3	3
4	1	5	2
5	1	6	2
6	1	46	22
7	1		
8	1		
9	1		
10	1		
11	1		
12	1		
13	1		
14	1		
15	1		22
1	2		
2	2	1	2
3	2	3	2
4	2	5	3
5	2	6	2
6	2	7	2
7	2	46	21
8	2		
9	2		
10	2		
11	2		
12	2		
13	2		
14	2		
15	2		21
1	3		
2	3	1	3
3	3	2	2
4	3	4	1
5	3	7	2
6	3	46	20
7	3		
8	3		
9	3		
10	3		
11	3		
12	3		
13	3		
14	3		
15	3		20
1	4		
2	4	3	1
3	4	7	3
4	4	8	3
5	4	10	4
6	4	43	5
7	4	44	7
8	4	46	19
9	4		
10	4		
11	4		
12	4		
13	4		
14	4		
15	4		19

TABLE 1. CONTINUED

NLAR	POINT	LMAT	MLINK
1	5		
2	5	1	2
3	5	2	3
4	5	3	4
5	5	6	2
6	5	7	3
7	5	11	1
8	5	46	21
9	5		
10	5		
11	5		
12	5		
13	5		
14	5		
15	5		21
1	6		
2	6	1	3
3	6	2	2
4	6	5	2
5	6	7	2
6	6	11	2
7	6	13	2
8	6	46	20
9	6		
10	6		
11	6		
12	6		
13	6		
14	6		
15	6		20
1	7		
2	7	2	2
3	7	3	2
4	7	4	3
5	7	5	3
6	7	6	2
7	7	8	2
8	7	9	1
9	7	46	19
10	7		
11	7		
12	7		
13	7		
14	7		
15	7		19
1	8		
2	8	4	3
3	8	7	2
4	8	9	1
5	8	10	1
6	8	46	19
7	8		
8	8		
9	8		
10	8		
11	8		
12	8		
13	8		
14	8		
15	8		19

TABLE 1. CONTINUED

NLAR	POINT	LMAT	MLINK
1	9		
2	9	7	1
3	9	8	1
4	9	46	20
5	9		
6	9		
7	9		
8	9		
9	9		
10	9		
11	9		
12	9		
13	9		
14	9		
15	9		20
1	10		
2	10	4	4
3	10	7	3
4	10	8	1
5	10	32	5
6	10	43	3
7	10	44	4
8	10	46	18
9	10		
10	10		
11	10		
12	10		
13	10		
14	10		
15	10		18
1	11		
2	11	5	1
3	11	6	2
4	11	12	1
5	11	13	2
6	11	46	22
7	11		
8	11		
9	11		
10	11		
11	11		
12	11		
13	11		
14	11		
15	11		22
1	12		
2	12	11	1
3	12	13	1
4	12	46	23
5	12		
6	12		
7	12		
8	12		
9	12		
10	12		
11	12		
12	12		
13	12		
14	12		
15	12		23

TABLE 1. CONTINUED

NLAR	POINT	LMAT	MLINK
1	13		
2	13	2	4
3	13	6	2
4	13	7	4
5	13	11	2
6	13	12	1
7	13	46	22
8	13		
9	13		
10	13		
11	13		
12	13		
13	13		
14	13		
15	13		22
1	14		
2	14	15	7
3	14	16	8
4	14	17	7
5	14	18	5
6	14	21	12
7	14	46	11
8	14		
9	14		
10	14		
11	14		
12	14		
13	14		
14	14		
15	14		11
1	15		
2	15	14	7
3	15	16	6
4	15	18	8
5	15	21	9
6	15	22	10
7	15	24	9
8	15	46	18
9	15		
10	15		
11	15		
12	15		
13	15		
14	15		
15	15		18
1	16		
2	16	14	8
3	16	15	6
4	16	17	1
5	16	21	5
6	16	22	6
7	16	46	12
8	16		
9	16		
10	16		
11	16		
12	16		
13	16		
14	16		
15	16		12

TABLE 1. CONTINUED

NLAR	POINT	LMAT	MLINK
1	17		
2	17	14	7
3	17	16	1
4	17	18	2
5	17	46	11
6	17		
7	17		
8	17		
9	17		
10	17		
11	17		
12	17		
13	17		
14	17		
15	17		11
1	18		
2	18	14	5
3	18	15	8
4	18	17	2
5	18	19	6
6	18	45	6
7	18	46	9
8	18		
9	18		
10	18		
11	18		
12	18		
13	18		
14	18		
15	18		9
1	19		
2	19	18	6
3	19	20	1
4	19	35	2
5	19	37	2
6	19	41	3
7	19	45	6
8	19	46	11
9	19		
10	19		
11	19		
12	19		
13	19		
14	19		
15	19		11
1	20		
2	20	19	1
3	20	21	2
4	20	31	4
5	20	34	5
6	20	35	2
7	20	36	4
8	20	46	12
9	20		
10	20		
11	20		
12	20		
13	20		
14	20		
15	20		12

TABLE 1. CONTINUED

NLAR	POINT	LMAT	MLINK
1	21		
2	21	15	9
3	21	16	5
4	21	20	2
5	21	22	2
6	21	26	3
7	21	31	2
8	21	46	13
9	21		
10	21		
11	21		
12	21		
13	21		
14	21		
15	21		13
1	22		
2	22	15	10
3	22	16	6
4	22	21	2
5	22	23	1
6	22	26	2
7	22	31	4
8	22	46	15
9	22		
10	22		
11	22		
12	22		
13	22		
14	22		
15	22		15
1	23		
2	23	22	1
3	23	24	1
4	23	25	2
5	23	46	16
6	23		
7	23		
8	23		
9	23		
10	23		
11	23		
12	23		
13	23		
14	23		
15	23		16
1	24		
2	24	15	9
3	24	23	1
4	24	25	2
5	24	27	5
6	24	46	17
7	24		
8	24		
9	24		
10	24		
11	24		
12	24		
13	24		
14	24		
15	24		17

TABLE 1. CONTINUED

NLAR	POINT	LMAT	MLINK
1	25		
2	25	23	2
3	25	24	2
4	25	26	1
5	25	27	4
6	25	46	17
7	25		
8	25		
9	25		
10	25		
11	25		
12	25		
13	25		
14	25		
15	25		17
1	26		
2	26	21	3
3	26	22	2
4	26	23	3
5	26	25	1
6	26	27	3
7	26	31	2
8	26	46	16
9	26		
10	26		
11	26		
12	26		
13	26		
14	26		
15	26		16
1	27		
2	27	24	5
3	27	25	4
4	27	26	3
5	27	28	2
6	27	30	2
7	27	31	4
8	27	32	4
9	27	46	19
10	27		
11	27		
12	27		
13	27		
14	27		
15	27		19
1	28		
2	28	12	12
3	28	27	2
4	28	29	8
5	28	46	21
6	28		
7	28		
8	28		
9	28		
10	28		
11	28		
12	28		
13	28		
14	28		
15	28		21

TABLE 1. CONTINUED

NLAR	POINT	LMAT	MLINK
1	29		
2	29	12	10
3	29	28	8
4	29	30	2
5	29	32	3
6	29	46	20
7	29		
8	29		
9	29		
10	29		
11	29		
12	29		
13	29		
14	29		
15	29		20
1	30		
2	30	27	2
3	30	28	4
4	30	29	2
5	30	31	3
6	30	32	2
7	30	46	18
8	30		
9	30		
10	30		
11	30		
12	30		
13	30		
14	30		
15	30		18
1	31		
2	31	20	4
3	31	21	2
4	31	22	4
5	31	26	2
6	31	27	4
7	31	30	3
8	31	33	4
9	31	38	4
10	31	46	15
11	31		
12	31		
13	31		
14	31		
15	31		15
1	32		
2	32	4	7
3	32	7	7
4	32	10	5
5	32	29	3
6	32	30	3
7	32	33	1
8	32	46	17
9	32		
10	32		
11	32		
12	32		
13	32		
14	32		
15	32		17

TABLE 1. CONTINUED

NLAR	POINT	LMAT	MLINK
1	33		
2	33	31	4
3	33	32	1
4	33	34	1
5	33	39	2
6	33	42	2
7	33	46	17
8	33		
9	33		
10	33		
11	33		
12	33		
13	33		
14	33		
15	33		17
1	34		
2	34	19	5
3	34	20	5
4	34	30	3
5	34	31	4
6	34	33	1
7	34	38	2
8	34	39	1
9	34	46	16
10	34		
11	34		
12	34		
13	34		
14	34		
15	34		16
1	35		
2	35	19	2
3	35	20	2
4	35	36	2
5	35	37	1
6	35	46	12
7	35		
8	35		
9	35		
10	35		
11	35		
12	35		
13	35		
14	35		
15	35		12
1	36		
2	36	20	3
3	36	31	5
4	36	35	2
5	36	37	2
6	36	38	1
7	36	41	1
8	36	46	13
9	36		
10	36		
11	36		
12	36		
13	36		
14	36		
15	36		13

TABLE 1. CONTINUED

NLAR	POINT	LMAT	MLINK
1	37		
2	37	18	7
3	37	19	2
4	37	35	1
5	37	36	2
6	37	41	1
7	37	45	4
8	37	46	11
9	37		
10	37		
11	37		
12	37		
13	37		
14	37		
15	37		11
1	38		
2	38	21	5
3	38	26	5
4	38	31	4
5	38	34	2
6	38	36	1
7	38	39	2
8	38	40	1
9	38	41	2
10	38	45	3
11	38	46	13
12	38		
13	38		
14	38		
15	38		13
1	39		
2	39	33	2
3	39	34	1
4	39	38	2
5	39	40	1
6	39	42	2
7	39	43	3
8	39	46	14
9	39		
10	39		
11	39		
12	39		
13	39		
14	39		
15	39		14
1	40		
2	40	38	1
3	40	39	1
4	40	41	1
5	40	42	2
6	40	43	3
7	40	45	2
8	40	46	13
9	40		
10	40		
11	40		
12	40		
13	40		
14	40		
15	40		13

TABLE 1. CONTINUED

NLAR	POINT	LMAT	MLINK
1	41		
2	41	18	8
3	41	36	1
4	41	37	1
5	41	38	2
6	41	40	1
7	41	45	3
8	41	46	12
9	41		
10	41		
11	41		
12	41		
13	41		
14	41		
15	41		12
1	42		
2	42	33	2
3	42	39	2
4	42	40	2
5	42	43	1
6	42	45	4
7	42	46	14
8	42		
9	42		
10	42		
11	42		
12	42		
13	42		
14	42		
15	42		14
1	43		
2	43	8	5
3	43	10	3
4	43	39	3
5	43	40	3
6	43	42	1
7	43	44	2
8	43	45	2
9	43	46	13
10	43		
11	43		
12	43		
13	43		
14	43		
15	43		13
1	44		
2	44	4	6
3	44	8	8
4	44	10	4
5	44	40	4
6	44	42	4
7	44	43	2
8	44	45	4
9	44	46	13
10	44		
11	44		
12	44		
13	44		
14	44		
15	44		13

TABLE 1. CONTINUED

NLAR	POINT	LMAT	MLINK
1	45		
2	45	18	6
3	45	38	3
4	45	40	2
5	45	41	3
6	45	43	2
7	45	44	4
8	45	46	11
9	45		
10	45		
11	45		
12	45		
13	45		
14	45		
15	45		11

Table 2 gives the INPUT MATRIX in a condensed form which shortens the time required to process data. Only a part of the complete matrix is shown and is intended to show the format that is used. Since changes are difficult to make in such a condensed matrix, users should always prepare Table 1.

Suggested route

The initial step of preparing the input data for a suggested route is to draw on a map a reasonably continuous bus route starting at any point, except the school, and to connect all points. "Reasonable" means a route that is rather logical, and an attempt is made to make the route a short route. Each suggested route should be of a different configuration from another suggested route. Figures 4, 5 and 6 are three examples of suggested routes each a different configuration. There is some indication that spiral routes (such as that given in Figure 6) will not yield as good routes solutions as some other configurations.

After the suggested route has been drawn, the next step is to prepare the data given in Table 2, namely, the number of students at each pick up point and identification of the levels for each point which directs the route to the next point to be visited.

The number of children at each bus stop must be obtained from the local school system.

Your attention is directed to Figure 4 in which the Suggested Bus Route Number 1 has been drawn. As may be seen, the route starts at Point Number 12, goes to 13, to 11, to 6, to 5, to 1, to 2, to 3, to 4, etc. Level values are given to tell the computer the direction of the route. For example, to go from Point 6 to Point 5, the level value is 4. In order to go from Point 5 to Point 1, the level value is 2. By using Table 1 and Figure 3 together the level values for all the points can be determined. In case of any difficulty in following these procedures, study carefully the footnote to Table 6, LMAT and MLINK and the sixth paragraph under Rationale above.

Therefore, we end with five fields of information for suggested routes:

a. The identification number of the pick up point

b. Indication of whether the pick up point is to be included in the present route (either 1 or 0_)

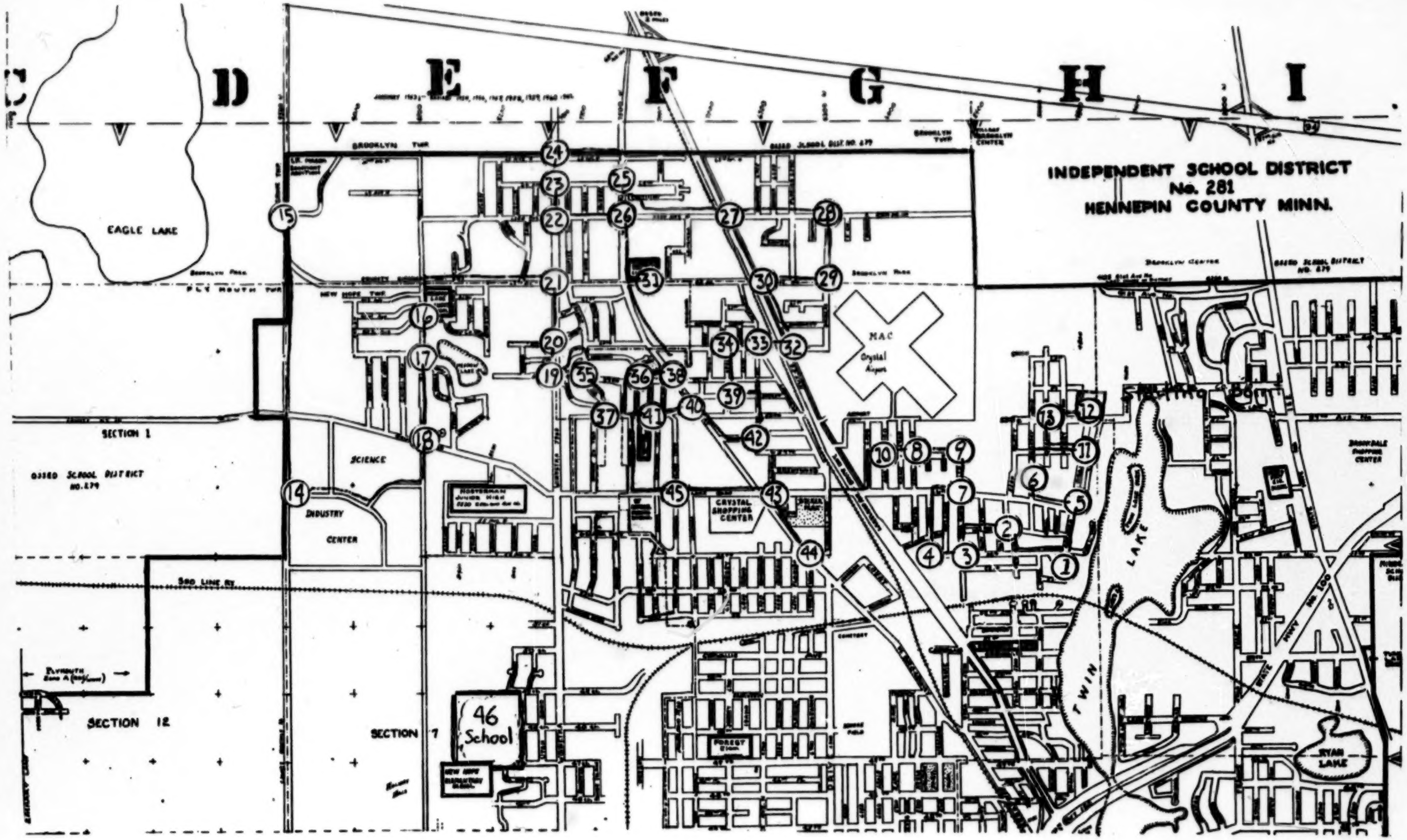
c. Number of children at each pick up point

d. Level identification

e. The identification number of each starting point. The number has no application when using suggested route data.

TABLE 2. CONDENSED LMAT AND MLINK MATRIX FOR FIRST 16 POINTS

```
000010000100000    000  020000100002    02000030000100003    03000040000100005    02
000050000100006    02000060000100046    22000070000100000    0000 080000100000    00
000090000100000    00000100000100000    000-0110000100000    00000120000100000    00
000130000100000    00000140000100000    00000150000100000    22000010000200000    00
000020000200001    02000030000200003    02000040000200005    03000050000200006    02
000060000200007    02000070000200046    21000080000200000    00000090000200000    00
000100000200000    00000110000200000    00000120000200000    00000130000200000    00
000140000200000    00000150000200000    21000010000300000    00000020000300001    03
000030000300002    02000040000300004    01000050000300007    02000060000300046    20
000070000300000    000 *080000300000    000   90000300000    00000100000300000    00
000110000300000    00000120000300000    00000130000300000    00000140000300000    00
000150000300000    20000010000400000    00000 20000400003    01000030000400007    03
000040000400008    03000050000400010    04000060000400043    05000070000400044    07
000080000400046    19000090000400000    00000100000400000    00000110000400000    00
000120000400000    00000130000400000    00000140000400000    00000150000400000    19
000010000500000    000  020000500001    02000030000500002    03000040000500003    04
000050000500006    02000060000500007    03000070000500011    01000080000500046    21
000090000500000    00000100000500000    00000110000500000    00000120000500000    00
000130000500000    00000140000500000    00000150000500000    21000010000600000    00
000020000600001    03000030000600002    02000040000600005    02000050000600007    02
000060000600011    02000070000600013    02000080000600046    20000090000600000    00
000100000600000    00000110000600000    00000120000600000    00000130000600000    00
000140000600000    00000150000600000    20000010000700000    00000020000700002    02
000030000700003    02000040000700004    03000050000700005    03000060000700006    02
000070000700008    02000080000700009    01000090000700046    19000100000700000    00
000110000700000    00000120000700000    00000130000700000    00000140000700000    00
000150000700000    19000010000800000    000   20000800004    03000030000800007    02
000040000800009    01000050000800010    01000060000800046    19000070000800000    00
000080000800000    000 *090000800000    00000100000800000    00000110000800000    00
000120000800000    00000130000800000    00000140000800000    00000150000800000    19
000010000900000    000 *020000900007    01000030000900008    01000040000900046    20
000050000900000    000 *060000900000    000 * 70000900000    0000*080000900000    00
000090000900000    00000100000900000    000 0110000900000    00000120000900000    00
000130000900000    00000140000900000    00000150000900000    20000010001000000    00
000020001000004    04000030001000007    03000040001000008    01000050001000032    05
000060001000043    03000070001000044    04000080001000046    18000090001000000    00
000100001000000    000 *110001000000    00* *120001000000    0000*130001000000    00
000140001000000    000 *150001000000    18000010001100000    00000020001100005    01
000030001100006    02000040001100012    01000050001100013    02000060001100046    22
000070001100000    000  080001100000    000 * 90001100000    00000100001100000    00
000110001100000    000*0120001100000    000 0130001100000    00000140001100000    00
000150001100000    22000010001200000    000 *020001200011    01000030001200013    01
000040001200046    23000050001200000    000 0 60001200000    00000070001200000    00
000080001200000    000 *090001200000    000 0100001200000    00000110001200000    00
000120001200000    00000130001200000    000 0140001200000    00000150001200000    23
000010001300000    000 *020001300002    04000030001300006    02000040001300007    04
000050001300011    02000060001300012    01000070001300046    22000080001300000    00
000090001300000    00000100001300000    00000110001300000    00000120001300000    00
000130001300000    00000140001300000    00000150001300000    22000010001400000    00
000020001400015    07000030001400016    08000040001400017    07000050001400018    05
000060001400021    12000070001400046    11000080001400000    00000090001400000    00
000100001400000    00000110001400000    00000120001400000    00000130001400000    00
000140001400000    00000150001400000    11000010001500000    00000020001500014    07
000030001500016    06000040001500018    08000050001500021    09000060001500022    10
000070001500024    09000080001500046    18000090001500000    00000100001500000    00
000110001500000    00000120001500000    000 0130001500000    00000140001500000    00
000150001500000    18000010001600000    00*   20001600014    08000030001600015    06
000040001600017    01000050001600021    05000060001600022    06000070001600046    12
```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I
INDEPENDENT SCHOOL DISTRICT
No. 281
HENNEPIN COUNTY MINN.
EAGLE LAKE
BROOKLYN TWP
OSSEO SCHOOL DIST NO. 279
SECTION 1
OSSEO SCHOOL DISTRICT NO. 279
SECTION 12
SECTION 7
SCIENCE
INDUSTRY
CENTER
MAC
Crystal Airport
CRYSTAL SHOPPING CENTER
TWIN
LAKE
RYAN LAKE
SOO LINE RY
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School
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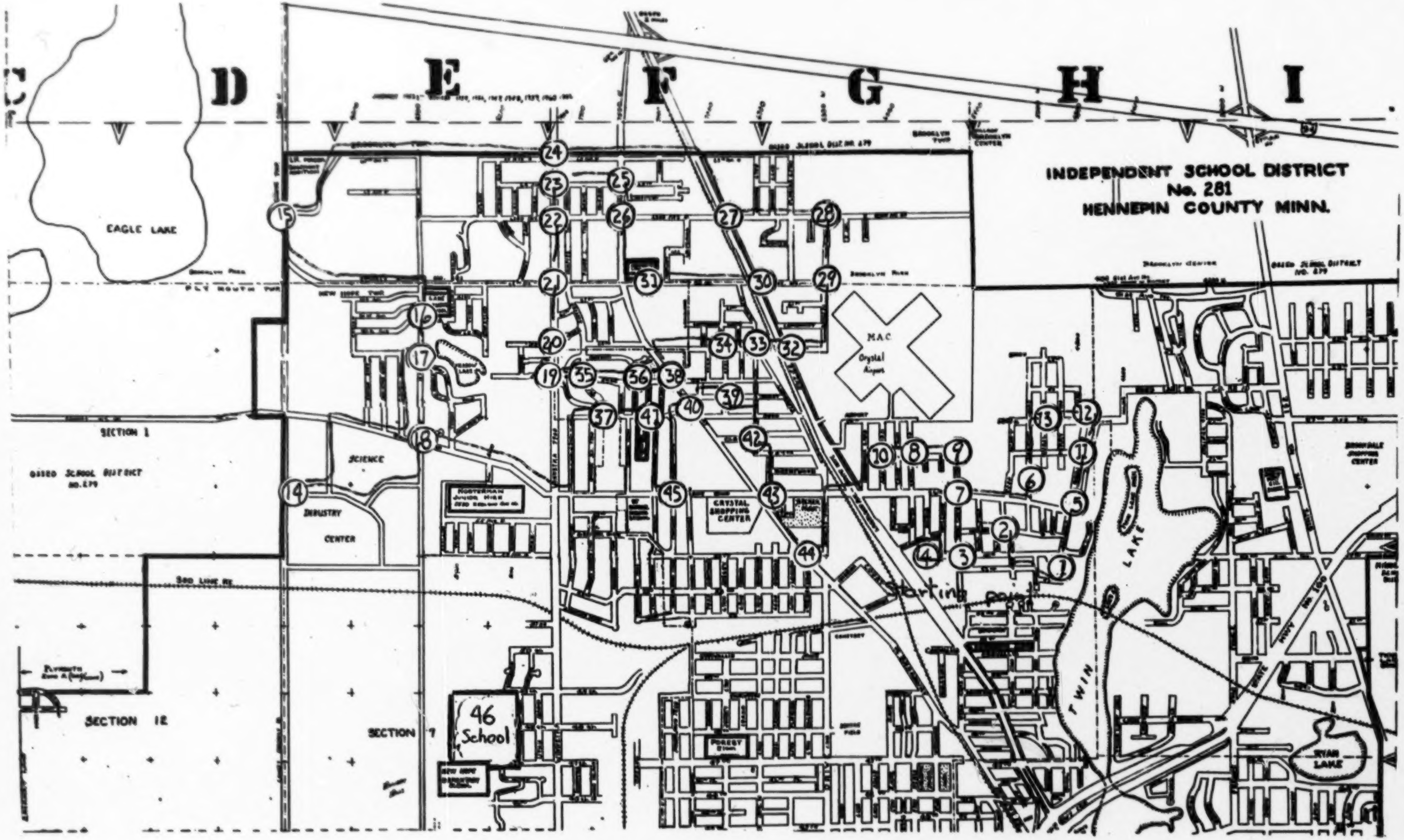
Figure 4. Suggested Route Number 1.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HENNEPIN COUNTY MINN.
EAGLE LAKE
SECTION 1
SECTION 12
SECTION 7
SCIENCE
INDUSTRY
CENTER
M.A.C.
Crystal
Airport
CRYSTAL
SHOPPING
CENTER
TWIN
LAKE
RYAN
LAKE
SOO LINE RR
Starting point
46
School
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5
6
7
8
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12
13
14
15
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19
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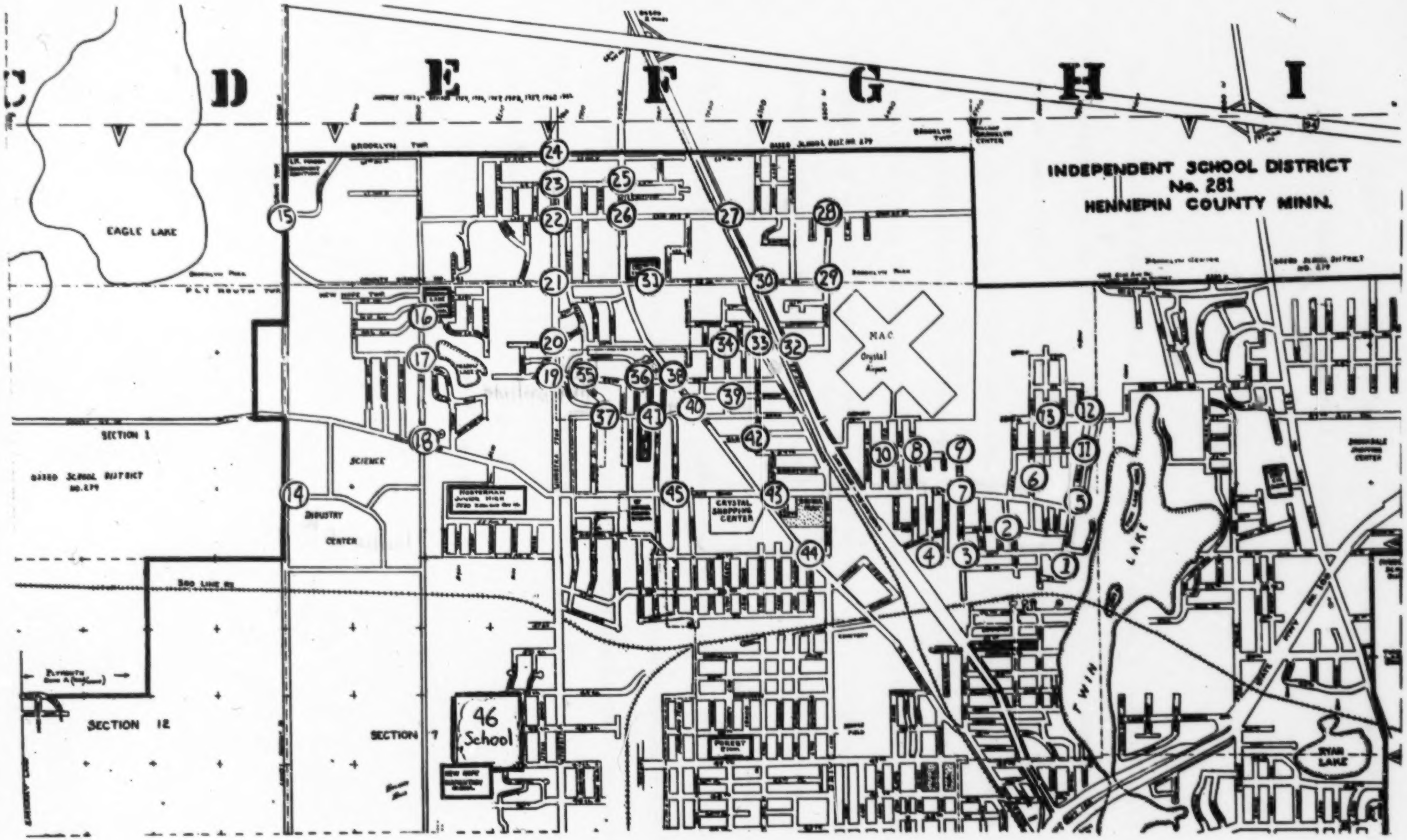
Figure 5. Suggested Route Number 2.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INDEPENDENT SCHOOL DISTRICT
No. 281
HENNEPIN COUNTY MINN.
EAGLE LAKE
BROOKLYN TWP
PLYMOUTH TWP
SECTION 1
SECTION 12
SECTION 7
SCIENCE
INDUSTRY
CENTER
MAC
Crystal
Airport
CRYSTAL
SHOPPING
CENTER
TWIN
LAKE
RYAN
LAKE
46
School
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Figure 6. Suggested Route Number 3.

For complete data for Suggested Route 1, see Table 3. Let us take Pick-up Point 15 as given in the table to clarify the meaning of the data which are as follows:

15 1 2 8 15

The first number, 15, identifies Pick-up Point 15. The second number, 1, indicates that this point is to be included in the present school bus route (a O would have indicated that the point has already been visited or that the point is not to be used). The third number, 2, indicates that there are 2 students to be transported from Pick-up Point 15. The fourth number, 8, is the level value for Point 15; and, by consulting Table 1, the eighth level for Point 15 indicates that the bus will go to Point 46, the school, from Point 15 (with a driving time of 18 minutes). Now returning to Figure 4, it may be noted that Point 15 is the last point in the system; and from there, the bus would go to the school. The fifth number indicates a starting point but has no application when using suggested routes but will in later solutions.

In drawing a suggested route, great care must be taken to see that the route joining all points can exist according to the INPUT MATRIX. The suggested route must be checked by hand using the matrix as given in Table 1. In many cases Table 1 values must have to be extended (increased number of points that can be visited for a particular point) in order for the suggested route to be possible. The caution noted in this paragraph cannot be over emphasized. In fact, most of the frustrations have been experienced with this part of the procedure.

Table 4 gives similar data for the Suggested Route 2.

TABLE 3. HEADER CARD NUMBER 2 AND DATA FOR SUGGESTED ROUTE NUMBER 1

46	11	12	1	46
1	1	16	2	1
2	1	12	3	2
3	1	2	4	3
4	1	11	3	4
5	1	14	2	5
6	1	7	4	6
7	1	15	8	7
8	1	8	5	8
9	1	8	3	9
10	1	24	7	10
11	1	7	3	11
12	1	7	3	12
13	1	19	5	13
14	1	3	2	14
15	1	2	8	15
16	1	21	4	16
17	1	18	4	17
18	1	32	2	18
19	1	8	3	19
20	1	12	3	20
21	1	12	3	21
22	1	33	6	22
23	1	27	2	23
24	1	13	3	24
25	1	9	3	25
26	1	7	7	26
27	1	14	3	27
28	1	9	3	28
29	1	7	3	29
30	1	2	4	30
31	1	4	9	31
32	1	6	6	32
33	1	12	3	33
34	1	26	6	34
35	1	22	2	35
36	1	10	5	36
37	1	16	4	37
38	1	9	6	38
39	1	5	3	39
40	1	20	5	40
41	1	17	6	41
42	1	22	3	42
43	1	16	8	43
44	1	10	7	44
45	1	1	5	45

TABLE 4. HEADER CARD NUMBER 2 AND DATA FOR SUGGESTED ROUTE NUMBER 2

46	11	4	1	46
1	1	16	4	1
2	1	12	2	2
3	1	2	3	3
4	1	11	2	4
5	1	14	7	5
6	1	7	5	6
7	1	15	8	7
8	1	8	5	8
9	1	8	3	9
10	1	24	7	10
11	1	7	4	11
12	1	7	3	12
13	1	19	3	13
14	1	3	4	14
15	1	2	7	15
16	1	21	3	16
17	1	18	3	17
18	1	32	2	18
19	1	8	3	19
20	1	12	3	20
21	1	12	5	21
22	1	33	5	22
23	1	27	4	23
24	1	13	5	24
25	1	9	4	25
26	1	7	7	26
27	1	14	5	27
28	1	9	4	28
29	1	7	5	29
30	1	2	7	30
31	1	4	7	31
32	1	6	7	32
33	1	12	4	33
34	1	26	7	34
35	1	22	2	35
36	1	10	4	36
37	1	16	2	37
38	1	9	6	38
39	1	5	5	39
40	1	20	7	40
41	1	17	4	41
42	1	22	3	42
43	1	16	6	43
44	1	10	7	44
45	1	1	5	45

Header card for suggested route

The header card for the suggested route will be referred to in the SPS Program as HEADER CARD 2 (HEADER CARD 1 will be described later) and will contain the following five items of information:

(N)	Number of pick up points
(NBUS)	Number of buses to be used
(NST)	Identification of the starting point
(NRTC)	Number of routes to be generated
(NRTU)	Number of points to be generated

In the case of the Suggested Route Number 1, 46 points will be used with 11 buses starting at Pick-up Point Number 12. Only one generated route is desired, and all 46 points are to be used in the generation. Therefore, the HEADER CARD Number 2 reads as follows:

46 11 12 1 46

List of buses for suggested route

The total number of students to be transported is obtained from the local transportation census. In the case of the 46 point system at Robbinsdale there were 575 students. For illustrative purposes it was estimated that 11 buses, each with a capacity of 54 students, could satisfactorily transport the 575 students. (It is to be noted that varying sizes of buses (KAP) could have been used.) Since there was no estimate as to how long any bus was to travel, upper limits on costs were not considered as will be the case in subsequent procedures.

The preparation of these data for the computer involved punching the capacity of each bus, which was 54, on eleven different cards in column 4 and 5. Should buses of other sizes be desirable, other values can be used. For example, if a school system had mostly 60 capacity buses, 60 would be used instead of 54.

Header Card for SPS School Bus Program

The header card for the SPS School Bus Program is called HEADER CARD NUMBER 1, and an example of this card is found in Table 5.

TABLE 5. HEADER CARD NUMBER 1 FOR SOLUTION 1

46 15 00 11 575 830

46	INDICATES NUMBER OF POINTS IN SYSTEM
15	INDICATES NLAR NUMBER OF LEVELS TO BE CONSIDERED FOR EACH POINT
00	NUMBER OF STUDENTS OVER THE CAPACITY OF THE BUS THAT MAY
11	NUMBER OF BUSES TO BE USED IN PRESENT SYSTEM
575	NUMBER OF PUPILS TO BE TRANSPORTED
830	TIME BUSES ARE TO ARRIVE AT SCHOOL

SPS SCHOOL BUS PROGRAM

The computer program presented in Table 6 is in Symbolic Programming System (SPS) for use with the IBM 1620 Computer with 60K storage. Every attempt was made to produce a readily comprehensible program; and, thus, many notes have been incorporated into Table 6. Furthermore, the footnote to the table is to be studied by all students.

Also the program is undergoing continuous changes; and should anyone be interested in the most recent development, a letter should be sent to the director of this project.

The reason for presenting the computer program in SPS is that originally flow charts were prepared, and from the charts a FORTRAN program was written. The FORTRAN program was successful, but the time required to process the data was too long. The use of the SPS program enables us to reduce the computer time by approximately one third. Furthermore, after changing from FORTRAN to SPS, several minor changes were introduced; and thus the FORTRAN program of two months ago is outdated.

```
*     TABLE 6. SCHOOL BUS SPS PROGRAM FOR CONDENSED MATRIX AND TIME UNITS
      ----------------------------------------------------------------------
      DORG 402                                                            10
*              READ HEADER CARD NUMBER 1 CONTAINING                       11
*              (N) NUMBER OF PICK UP POINTS                               12
*              (NLAR) NUMBER OF LEVELS AT EACH POINT                      13
*              (NOVER) MAX. AMOUNT OF OVER LOAD                           14
*              (NBUS) NUMBER OF BUSES TO BE USED                          15
*              (KDIST) TOTAL NUMBER OF STUDENTS                           16
*              (NTIME) SCHOOL STARTING TIME                               17
      RNCDRD+1                                                            20
      SF   RD+1                                                           30
      SF   RD+6                                                           40
      SF   RD+11                                                          50
      SF   RD+16                                                          60
      SF   RD+21                                                          70
      SF   RD+26                                                          80
      TF   N,RD+5                                                         90
      TF   NLAR,RD+10                                                    100
      TF   NOVER,RD+15                                                   110
      TF   NBUS,RD+20                                                    120
      TF   KIDST,RD+25                                                   130
*             CONVERSION OF STARTING TIME TO MINUTES                     131
      TF   HTAA,RD+30                                                    140
      TF   NTIME,RD+28                                                   150
      MM   NTIME,40                                                      160
      SF   95                                                            170
      TF   NTIME,RD+30                                                   180
      S    NTIME,99                                                      190
      TF   HT,NTIME                                                      200
*             (KK) BUS NUMBER                                            201
```

TABLE 6. CONTINUED

```
          TFM KK,1
          TFM I,0
*                READ (KAP) THE CAPACITY FOR EACH BUS
*                (MILE) MAX DISTANCE EACH BUS IS TO BE DRIVEN
*                ALL GENERATED ROUTES EQUAL TO OR LESS THAN
*                (MILE) ARE TO BE PUNCHED
R402      RNCDRD+1
          SF   RD+1
          SF   RD+6
          TFM  AA+6,KAP
          TFM  AB+6,MILE
          MM   I,5
          SF   95
          A    AA+6,99
          A    AB+6,99
AA        TF   KAP,RD+5
AB        TF   MILE,RD+10
          AM   I,1
          C    I,NBUS
          BE   A402
          B    R402
*               (NRC) INTERNAL COUNTER FOR NUMBER OF
*               ROUTES TO BE GENERATED
A402      TFM NRC,0
          TF   M,N
          SM   M,1
*         START
          CF   AC
*               INTERNAL COUNTER FOR READING IN THE
*               CONDENSED MATRIX
```

TABLE 6. CONTINUED

```
      TFM KZ,4
*     END
*            IF CONSOLE SWITCH 4 IS ON, READ(LMAT)
*            THE LIST CONTAINING THE FEASIBLE PICK-UP
*            POINT THAT CAN BE CONSIDERED FROM ANY
*            GIVEN POINT, AND (MLINK) THE MILEAGES
*            OR TIME BETWEEN THE RESPECTIVE PICK-UP
*            POINTS
      BC4 A907
      B   A908
A907  TFM I,0
AC    TFM J,0
*     START
***************
*     NOTE
*     THIS PROGRAM WILL READ IN EITHER THE CONDENSED
*     OR REGULAR MATRIX
      TFM AGE+1,32,10
      TFM AGEE+1,16,10
***************
AD    BNF ADXX,AC
      B   ACAC
ADXX  TFM ACAC+11,RD+40
      RNCD RD+1
      SF  RD+1
      SF  RD+21
***************
      C   RD+80,ZEROX
      BNE *+24
AGEE  TFM AGE+1,41,10
```

*.   TABLE 6. CONTINUED

```
      TFM AGEE+1,41,10                                  556
***************                                         557
      SF   RD+41                                        560
      SF   RD+61.                                       570
AGE   SF   AC                                           580
      B    ADAD                                         590
ACAC  TF   RD+20,RD+40                                  600
      AM   ACAC+11,20                                   610
      SM   KZ,1                                         620
      BD   ADAD,KZ                                      630
      TFM  KZ,4.                                        640
      CF   AC                                           650
      B    AD                                           660
*     END                                               670
ADAD  SF   RD+1                                         680
      SF   RD+6                                         690
      SF   RD+11                                        700
      SF   RD+16                                        710
      TF   JA,RD+5                                      720
      TF   IA,RD+10                                     730
      SM   JA,1                                         740
      SM   IA,1                                         750
      TFM  BA+6,LMAT                                    760
      TFM  BB+6,MLINK                                   770
      MM   JA,5                                         780
      SF   95                                           790
      A    BA+6,99                                      800
      A    BB+6,99                                      810
      MM   IA,100                                       820
      SF   95                                           830
```

* TABLE 6. CONTINUED

```
        A     BA+6,99                                           840
        A     BB+6,99                                           850
BA      TF    LMAT,RD+15                                        860
BB      TF    MLINK,RD+20                                       870
        AM    J,1                                               880
        C     J,NLAR                                            890
        BE    *+24                                              900
        B     AD                                                910
        AM    I,1                                               920
        C     I,M                                               930
        BE    A100                                              940
        B     AC                                                950
A100    NOP                                                     960
*                READ HEADER CARD NUMBER 2 CONTAINING          0961
*                (N) NUMBER OF PICK UP POINTS                  0962
*                (NBUS) NUMBER OF BUSES TO BE USED             0963
*                (NST) IDENTIFICATION NUMBER OF STARTING POINT 0964
*                (NRTC) NUMBER OF ROUTES TO BE COMPUTED        0965
*                (NPTU) NUMBER OF POINTS TO BE USED IN         0966
*                CURRENT GENERATIONS                           0967
A908    RNCDRD+1                                                970
        SF    RD+1                                              980
        SF    RD+6                                              990
        SF    RD+11                                            1000
        SF    RD+16                                            1010
        SF    RD+21                                            1020
        TF    N,RD+5                                           1030
        TF    NBUS,RD+10                                       1040
        TF    NST,RD+15                                        1050
        TF    NRTC,RD+20                                       1060
```

TABLE 6. CONTINUED

```
       TF   NPTU,RD+25                                                1070
*           INITIALIZING FIELDS                                       1071
       TFM  I,0                                                       1080
       TFM  CA+6,NX                                                   1090
       TFM  CB+6,NP                                                   1100
       TFM  CC+6,KIDS                                                 1110
       TFM  CD+6,LMAT                                                 1120
       TFM  CE+6,NSR                                                  1130
*           READ IN A LIST CONTAINING                                 1131
*           (NX) LIST OF ALL PICK-UP POINTS                           1132
*           (NP) INDICATES IF THE POINT IS TO BE                      1133
*           CONSIDERED ON THE PRESENT ROUTE                           1134
*           (KIDS) NUMBER OF STUDENTS AT EACH                         1135
*           PICK-UP POINT                                             1136
*           LMAT(I,1) LEVEL AT WHICH YOU ARE OPERATING                1137
*           (NSR) LIST OF POINTS THAT MAY BE USED AS                  1138
*           STARTING POINTS                                           1139
C100   RNCDRD+1                                                       1140
       SF   RD+1                                                      1150
       SF   RD+6                                                      1160
       SF   RD+11                                                     1170
       SF   RD+16                                                     1180
       SF   RD+21                                                     1190
CA     TF   NX,RD+5                                                   1200
CB     TF   NP,RD+10                                                  1210
CC     TF   KIDS,RD+15                                                1220
CD     TF   LMAT,RD+20                                                1230
CE     TF   NSR,RD+25                                                 1240
       AM   CA+6,5                                                    1250
       AM   CB+6,5                                                    1260
```

TABLE 6. CONTINUED

```
       AM   CC+6,5                                                       1270
       AM   CD+6,100                                                     1280
       AM   CE+6,5                                                       1290
       AM   I,1                                                          1300
       C    I,M                                                          1310
       BE   A403                                                         1320
       B    C100                                                         1330
*               SINCE NP(N) IS THE SCHOOL AND SINCE IT                   1331
*               HAS TO BE INCLUDED, THIS POINT IS INDICATED              1332
*               AS VISITED ON THE INITIAL PERIOD                         1333
A403   MM   N,5                                                          1340
       SF   95                                                           1350
       SM   99,5                                                         1360
       TFM  CF+6,NP                                                      1370
       A    CF+6,99                                                      1380
CF     TFM  NP,1                                                         1390
*               (KOUNT) INTERNAL COUNTER TO COUNT THE                    1391
*               NUMBER OF POINTS VISITED                                 1392
*               CARD 1400 IS THE BEGINING OF THE                         1393
*               GENERATION OF A ROUTE AND CARD 2200 IS                   1394
*               THE END OF THIS GENERATION                               1395
A500   TFM  KOUNT,1                                                      1400
*               A MEANS OF LOCATING THE STARTING POINT IN                1401
*               THE NX LIST                                              1402
A501   BTM  MULT,NST                                                     1410
       TFM  CG+11,NSR                                                    1420
       A    CG+11,99                                                     1430
CG     TF   NX,NSR                                                       1440
*               INCREMENT THE INTERNAL COUNTER (I) TO THE                1441
*               STARTING POINT                                           1442
*                         TABLE 6. CONTINUED
      TF   I,CG+11,11                                                  1450
*               SUBTRACT 1 FROM NP(I) TO INDICATE THAT                 1451
*               THIS POINT (SCHOOL) HAS BEEN VISITED                   1452
      BTM  MULT,I                                                      1460
      TFM  CH+6,NP                                                     1470
      A    CH+6,99                                                     1480
CH    SM   NP,1                                                        1490
*               INITIALIZE THE INTERNAL COUNTER (K) TO                 1491
*               THE PRESENT OPERATING LEVEL                            1492
A502  BT   MT,*+23                                                     1500
CHH   NOP  I,ONE,2                                                     1510
      AM   99,LMAT                                                     1520
      TF   K,99,11                                                     1530
      BT   MT,*+23                                                     1540
      NOP  I,K,2                                                       1550
      AM   99,LMAT                                                     1560
*               CHECK TO SEE IF THE POINT IS BEYOND THE                1561
*               ARRAY LISTING THE FEASIBLE POINTS                      1562
      CM   99,0,610                                                    1570
      BP   A503                                                        1580
      B    A508                                                        1590
*               CHECK TO SEE IF THE POINT IS SCHOOL WHICH              1591
*               IS ALWAYS THE LAST POINT IN EACH ARRAY                 1592
A503  C    99,N,6                                                      1600
      BN   A504                                                        1610
      B    A506                                                        1620
A504  TF   II,99,11                                                    1630
      BTM  MULT,II                                                     1640
      AM   99,NP                                                       1650
*               CHECK TO SEE IF THIS POINT HAS BEEN VISITED            1651
```

```
*.                       TABLE 6. CONTINUED
      CM   99,0,610                                                1660
      BP   A505                                                    1670
      B    A507                                                    1680
*           FROM 1690 TO 1760, ADD THIS POINT TO THE               1681
*           BUS ROUTE                                              1682
A505  AM   KOUNT,1                                                 1690
      TF   I,II                                                    1700
      BTM  MULT,I                                                  1710
      AM   99,NP                                                   1720
      SM   99,1,610                                                1730
      BTM  MULT,KOUNT                                              1740
      AM   99,NX                                                   1750
      TF   99,I,6                                                  1760
*           HAVE ALL POINTS BEEN VISITED, IF ALL POINTS            1761
*           HAVE BEEN VISITED COMPUTE THE COST OF                  1762
*           THIS ROUTE, OTHERWISE, GENERATE THE NEXT POINT         1763
      C    KOUNT,NPTU                                              1770
      BN   A502                                                    1780
      B    A199                                                    1790
*           FROM CARD 1800 THRU CARD 220 ANY                       1791
*           UNSATISFACTORY POINT IS SUBTRACTED OUT                 1792
*           AND THE LEVEL OF THE PREVIOUS POINT IS                 1793
*           INCREMENTED SO THAT ANOTHER POINT MAY                  1794
*           BE GENERATED                                           1795
A506  C    KOUNT,M                                                 1800
      BZ   A504                                                    1810
A507  BT   MT,CHH+11                                               1820
      AM   99,LMAT                                                 1830
      AM   99,1,610                                                1840
      B    A502                                                    1850
```

TABLE 6. CONTINUED

```
A508  SM   KOUNT,1                                  1860
      CM   KOUNT,0                                  1870
      BN   A710                                     1880
      BZ   A510                                     1890
A509  BTM  MULT,KOUNT                               1900
      AM   99,NX                                    1910
      TF   I,99,11                                  1920
      AM   99,5                                     1930
      TF   K,99,11                                  1940
      BTM  MULT,K                                   1950
      AM   99,NP                                    1960
      AM   99,1,610                                 1970
      BT   MT,*+23                                  1980
BHH   NOP  K,ONE,2                                  1990
      AM   99,LMAT                                  2000
      TFM  99,2,67                                  2010
      BT   MT,CHH+11                                2020
      AM   99,LMAT                                  2030
      AM   99,1,610                                 2040
      B    A502                                     2050
A510  AM   NST,1                                    2060
      BTM  MULT,KOUNT                               2070
      AM   99,5                                     2080
      AM   99,NX                                    2090
      TF   K,99,11                                  2100
      BTM  MULT,K                                   2110
      AM   99,NP                                    2120
      AM   99,1,610                                 2130
      BT   MT,BHH+11                                2140
      AM   99,LMAT                                  2150
      TFM 99,2,67                                           2160
A511  BTM MULT,NST                                          2170
      AM  99,NSR                                            2180
      CM  99,0,67                                           2190
      BP  A500                                              2200
A711  BC2 A800                                              2210
*               ERROR CODES                                 2211
A712  H                                                     2220
A710  WACDF77                                               2230
      H                                                     2240
*               INITIALIZE FIRST ROUTE AND INTERNAL COUNTER 2241
A199  AM  NRC,1                                             2250
      TFM L1,0                                              2260
*               ZERO COST VALUES                            2261
*               (MAT) STORAGE FOR ROUTE PRIOR TO OUTPUT     2262
*               (MAT2) STORAGE FOR PICK UP POINTS           2263
*               (NT) STORAGE FOR PICK UP TIMES              2264
*               (KKS) TOTAL STUDENT MILES OR TIME           2265
*               (NPU) TOTAL MILEAGE FOR EACH BUS            2266
*               (LLOAD) TOTAL NUMBER OF STUDENTS ON EACH    2267
*               BUS                                         2268
      TFM J,0                                               2270
      TFM AJ+6,MAT2                                         2280
      TFM AH+6,MAT                                          2290
*     START                                                 2300
      TFM A5,5                                              2310
      TFM AJA+11,400                                        2320
      TFM AKK+6,NT                                          2330
      BNC2 AH                                               2340
      TFM AJA+11,20                                         2350
```

```
*                         TABLE 6. CONTINUED
        TFM A5,100                                                    2360
AH      TFM MAT,0                                                     2370
AJ      TFM MAT2,0                                                    2380
        AM  J,1                                                       2390
AKK     TFM NT,0                                                      2400
        AM  AKK+6,5                                                   2410
        A   AH+6,A5                                                   2420
        A   AJ+6,A5                                                   2430
AJA     CM  J,400                                                     2440
*       END                                                           2450
        BNE AH                                                        2460
        TFM NPU,0                                                     2470
        TFM KKS,0                                                     2480
        TFM KKOST,0                                                   2490
        TFM LLOAD,0                                                   2500
        TFM K,1                                                       2510
*              (KTAB) INTERNAL COUNTER                                2511
        TFM KTAB,0                                                    2520
*              IS THIS ACCOUNTING FOR A SUGGESTED ROUTE               2521
*              OR FOR ALL POSSIBLE ROUTES                             2522
A40     BC2 A900                                                      2530
        TF  KK,K                                                      2540
A900    TFM L,1                                                       2550
*              (MIN) THE CAPACITY OF EACH BUS                         2551
*              (MAX) THE CAPACITY OF EACH BUS PLUS THE                2552
*              AMOUNT OF OVERLOAD ALLOWED (NOVER)                     2553
        BTM MULT,KK                                                   2560
        AM  99,KAP                                                    2570
        TF  MAX,99,11                                                 2580
        TF  MIN,99,11                                                 2590
```

```
*.                     TABLE 6. CONTINUED
---------------------------------------------------------------------------
        A    MAX,NOVER                                              2600
*                ZERO CONSTANTS                                     2601
*                (LOAD) NUMBER OF STUDENTS ON EACH BUS              2602
*                (KOSTS) STUDENT MILES FOR EACH BUS                 2603
*                (LO) NUMBER OF STUDENTS OVER THE CAPACITY          2604
*                OF A GIVEN BUS AT ANY POINT (LEFT-OVER)            2605
        TFM  LOAD,0                                                 2610
        TFM  KOSTS,0                                                2620
        TFM  KOST,0                                                 2630
*                FROM 2650 TO 2980 PICK UP A POINT FROM             2641
*                THE (NX) LIST, ADD KIDS TO LOAD AND ADD            2642
*                KOST TO THE TOTAL KOST OF THIS ROUTE               2643
        TFM  LO,0                                                   2640
A304    AM   L1,1                                                   2650
        BTM  MULT,L1                                                2660
        AM   99,NX                                                  2670
        TF   MP,99,11                                               2680
        BT   MT,*+23                                                2690
        NOP  MP,ONE,2                                               2700
        AM   99,LMAT                                                2710
        TF   MR,99,11                                               2720
A305    BTM  MULT,MP                                                2730
        AM   99,KIDS                                                2740
        A    LOAD,99,11                                             2750
        S    LOAD,NPU                                               2760
        TF   SAVE,99                                                2770
        BT   MT,*+23                                                2780
AHH     NOP  L,KK,2                                                 2790
        AM   99,MAT2                                                2800
        TF   99,SAVE,611                                            2810
```

*

TABLE 6. CONTINUED

```
      S    99,NPU,6                                          2820
      TFM  NPU,0                                             2830
      TFM  LO,0                                              2840
*     START                                                  2850
      BT   MT,*+23                                           2860
      NOP  KK,L,2                                            2870
      AM   99,NT                                             2880
      TF   A33+6,99                                          2890
*     END                                                    2900
      BT   MT,*+23                                           2910
      NOP  MP,MR,2                                           2920
      TF   SAVE,99                                           2930
      AM   99,MLINK                                          2940
      A    KOST,99,11                                        2950
*     START                                                  2960
A33   TF   NT,99,11                                          2970
*     END                                                    2980
*              CHECK TO SEE IF THE NUMBER OF KIDS FILL       2981
*              THE BUS                                       2982
      C    LOAD,MIN                                          2990
      BN   A309                                              3000
      B    A308                                              3010
*              CHECK TO SEE IF THE NUMBER OF KIDS AT THE     3011
*              PICK UP POINT WILL OVERLOAD THE BUS           3012
A308  C    LOAD,MAX                                          3020
      BP   A314                                              3030
      C    L1,M                                              3031
      BNE  A315                                              3032
      S    NBUS,K                                            3033
      TF   KTAB,NBUS                                         3034
```

TABLE 6. CONTINUED

```
*
      A    NBUS,K                                              3035
      TF   K,NBUS                                              3036
      B    A315                                                3037
*               ADD TO KOSTS THE KOSTS OF TRAVELING TO         3040
*               THIS POINT                                     3041
A309  BT   MT,AHH+11                                           3050
      AM   99,MAT                                              3060
      TF   99,MP,6                                             3070
      AM   SAVE,MLINK                                          3080
      M    LOAD,SAVE,11                                        3090
      SF   95                                                  3100
      A    KOSTS,99                                            3110
      SM   SAVE,MLINK                                          3120
      AM   L,1                                                 3130
      TF   ABC+11,LLOAD                                        3140
      A    ABC+11,LOAD                                         3150
*               HAVE ALL THE KIDS IN THE SYSTEM BEEN           3151
*               PICKED UP. IF ALL KIDS HAVE NOT BEEN           3152
*               PICKED UP, GO TO THE NEXT POINT TO BE          3153
*               VISITED                                        3154
ABC   CM   KIDST,0                                             3160
      BNZ  A304                                                3170
*               THIS SECTION ASSURES THAT ONLY THE LOADED      3171
*               BUSES ARE CONSIDERED WHEN PUNCHING             3172
      S    NBUS,K                                              3180
      TF   KTAB,NBUS                                           3190
      A    NBUS,K                                              3200
      TF   K,NBUS                                              3210
      B    A316                                                3220
*               IF THE BUS HAS BEEN OVERLOADED TAKE OFF        3221
*                         TABLE 6. CONTINUED
*                ENOUGH KIDS TO FILL THE BUS. PREPARE TO            3222
*                SEND THE BUS TO SCHOOL AND PREPARE TO              3223
*                START ANOTHER BUS AT THIS POINT                    3224
A314   TF   LO,LOAD                                                 3230
       S    LO,MAX                                                  3240
       BTM  MULT,MP                                                 3250
       AM   99,KIDS                                                 3260
       TF   SAVE,99                                                 3270
       TF   NPU,99,11                                               3280
       S    NPU,LO                                                  3290
       S    LOAD,SAVE,11                                            3300
       A    LOAD,NPU                                                3310
       SM   L1,1                                                    3320
*                CARD 3330 TO CARD 3860 IS THE BOOKEEPING           3321
*                SECTION OF THE PROGRAM.  ONCE A BUS IS             3322
*                LOADED, THE COST ITEMS ARE STORED FOR              3323
*                LATER USE                                          3324
A315   BT   MT,AHH+11                                               3330
       AM   99,MAT                                                  3340
       TF   99,MP,6                                                 3350
       BT   MT,AHH+11                                               3360
       AM   99,MAT2                                                 3370
       TF   SAVE,99                                                 3380
       BTM  MULT,MP                                                 3390
       AM   99,KIDS                                                 3400
       TF   SAVE,99,611                                             3410
       S    SAVE,LO,6                                               3420
       BT   MT,*+23                                                 3430
DHH    NOP  MP,MR,2                                                 3440
       AM   99,MLINK                                                3450
```

```
*.                       TABLE 6. CONTINUED
*      START                                                   3460
       TF   BXA+11,99                                          3470
*      END                                                     3480
       S    KOST,99,11                                         3490
       BT   MT,*+23                                            3500
       NOP  MP,NLAR,2                                          3510
       AM   99,MLINK                                           3520
*      START                                                   3530
       TF   BXB+11,99                                          3540
*      END                                                     3550
       TF   SAVE,99                                            3560
       A    KOST,99,11                                         3570
       M    LOAD,SAVE,11                                       3580
       SF   95                                                 3590
       A    KOSTS,99                                           3600
*      START                                                   3610
       BT   MT,*+23                                            3620
       NOP  KK,L,2                                             3630
       AM   99,NT                                              3640
BXA    S    99,MLINK,6                                         3650
BXB    A    99,MLINK,6                                         3660
*      END                                                     3670
A316   A    LLOAD,LOAD                                         3680
       A    KKOST,KOST                                         3690
A399   BT   MT,*+23                                            3700
       NOP  TWO,KK,2                                           3710
       AM   99,MZ                                              3720
       TF   99,LOAD,6                                          3730
       BT   MT,*+23                                            3740
       NOP  ONE,KK,2                                           3750
```

TABLE 6. CONTINUED

```
      AM   99,MZ                                                    3760
      TF   99,KOSTS,6                                               3770
      A    KKS,KOSTS                                                3780
      BT   MT,*+23                                                  3790
      NOP  THREE,KK,2                                               3800
      AM   99,MZ                                                    3810
      TF   99,KOST,6                                                3820
      C    K,NBUS                                                   3830
      BE   A400                                                     3840
      AM   K,1                                                      3850
      B    A40                                                      3860
*               PREPARE TO PUNCH ROUTES AND COST                    3861
A400  TFM  I,1                                                      3870
      S    NBUS,KTAB                                                3880
*               IF CONSOLE SWITCH 2 IS NOT ON THIS IS               3881
*               A SUGGESTED ROUTE, GO TO A903 AND PUNCH             3882
*               ALL THE ROUTES.  OTHERWISE GO TO A902 AND           3883
*               COMPARE KKOST TO THE MILE FOR THAT ROUTE.           3884
*               IF KKOST IS LESS PUNCH THE ROUTE OTHERWISE          3885
*               SELECT THE NEXT ROUTE.                              3886
AXAX  BC2  A902                                                     3890
      B    A903                                                     3900
A902  TF   I,KK                                                     3910
      BTM  MULT,KK                                                  3920
      AM   99,MILE                                                  3930
      C    KKOST,99,11                                              3940
      BP   A698                                                     3950
A903  TNF  F12+20,I                                                 3960
      BT   ZSUB+12,*+20                                             3970
      NOP  F12+5*2+2,05000,2                                        3980
```

```
*                     TABLE 6. CONTINUED
*                PUNCH BUS NUMBER                                     3981
        WACD F12+2,,,        FIRST CARD PUNCHED                       3990
*                FROM CARD 4000 TO CARD 4500 THE PICK UP              3991
*                POINTS, NUMBER OF KIDS AT EACH POINT,                3992
*                KOSTS, LOAD, AND KOST ARE SET UP IN                  3993
*                THE OUTPUT AREAS                                     3994
        TFM KX,1                                                      4000
        TFM PA+6,OUT+4*2 - 2                                          4010
        TFM PB+6,OUT+1*2 - 2                                          4020
        TFM PC+6,OUTA+4*2-2                                           4030
        TFM PD+6,OUTA+1*2-2                                           4040
PP      BT  MT,*+23                                                   4050
        NOP KX,I,2                                                    4060
        AM  99,MAT2                                                   4070
        SM  99,3                                                      4080
        SF  99,,6                                                     4090
        AM  99,3                                                      4100
PA      TNF OUT+4*2-2,99,11                                           4110
        BT  ZSUB+12,*+20                                              4120
PB      NOP OUT+1*2-2,04000,2                                         4130
        SM  99,3                                                      4140
        CF  99,,6                                                     4150
        AM  99,3                                                      4160
        AM  PA+6,8                                                    4170
        AM  PB+6,8                                                    4180
        SM  99,MAT2                                                   4190
        AM  99,MAT                                                    4200
        SM  99,3                                                      4210
        SF  99,,6                                                     4220
        AM  99,3                                                      4230
```

*   TABLE 6. CONTINUED

```
PC      TNF OUTA+4*2-2,99,11                                        4240
        BT  ZSUB+12,*+20                                            4250
PD      NOP OUTA+1*2-2,04000,2                                      4260
        SM  99,3                                                    4270
        CF  99,,6                                                   4280
        AM  99,3                                                    4290
        AM  PC+6,8                                                  4300
        AM  PD+6,8                                                  4310
        CM  KX,16                                                   4320
        BE  *+36                                                    4330
        AM  KX,1                                                    4340
        B   PP                                                      4350
        TFM PE+6,OUTA+66*2-2                                        4360
        TFM KZ,1                                                    4370
        TFM PF+6,OUTA+70*2-2                                        4380
PPP     BT  MT,*+23                                                 4390
        NOP KZ,I,2                                                  4400
        AM  99,MZ                                                   4410
PF      TNF OUTA+65*2-2,99,11                                       4420
        BT  ZSUB+12,*+20                                            4430
PE      NOP OUTA+61*2-2,05000,2                                     4440
        AM  PE+6,10                                                 4450
        AM  PF+6,10                                                 4460
        CM  KZ,3                                                    4470
        BE  *+36                                                    4480
        AM  KZ,1                                                    4490
        B   PPP                                                     4500
        WACD OUT,,,         SECOND CARD PUNCHED                     4510
*                 PUNCH PICK UP POINTS, KOSTS, LOAD, KOST           4501
*                 PUNCH NUMBER OF KIDS AT EACH POINT                4511
*                       TABLE 6. CONTINUED
        WACD OUTA,,,        THIRD CARD PUNCHED                          4520
*       START                                                           4530
        TF   HT,NTIME                                                   4540
        BT   MT,*+23                                                    4550
        NOP  I,S16,2                                                    4560
        AM   99,NT                                                      4570
        TF   BXC+11,99                                                  4580
        TFM  KX,1                                                       4590
        TFM  BXE+6,OUTR+64*2-2                                          4600
        TFM  BXD+6,OUTR+61*2-2                                          4610
BXC     S    HT,NT                                                      4620
        LD   99,HT                                                      4630
        DM   95,60,10                                                   4640
        TF   HTA-2,97                                                   4650
        SF   HTA-3                                                      4660
        TF   HTA,99                                                     4670
        CF   HTA-1                                                      4680
        C    HTAA,HTA                                                   4690
        BNE  *+24                                                       4700
        TFM  HTA,0,8                                                    4710
BXE     TNF  OUTR+64*2-2,HTA                                            4720
        BT   ZSUB+12,*+20                                               4730
BXD     NOP  OUTR+61*2-2,04000,2                                        4740
        SM   BXC+11,5                                                   4750
        SM   BXE+6,8                                                    4760
        SM   BXD+6,8                                                    4770
        CM   KX,16                                                      4780
        BE   *+36                                                       4790
        AM   KX,1                                                       4800
        B    BXC                                                        4810
```

```
*.                     TABLE 6. CONTINUED
*                 PUNCH PICK-UP TIMES                                 4811
         WACD OUTR,,,         FOURTH CARD PUNCHED                     4820
*        END                                                          4830
         BC2 APPA                                                     4840
         WACDOUTT,,,               BLANK CARD PUNCHED                 4850
*                 IS THIS THE LAST ROUTE TO BE PUNCHED                4851
         C    I,NBUS                                                  4860
         BE   *+36                                                    4870
         AM   I,1                                                     4880
         B    AXAX                                                    4890
*                 SET UP TOTAL COST (KKOSTS) FOR THE SYSTEM           4891
APPA     TFM COUNT,0                                                  4900
         TFM PM+6,OUTC+5*2-2                                          4910
         TFM PN+6,OUTC+1*2-2                                          4920
         TFM PM+11,TAB,711                                            4930
PM       TNF OUTC+5*2-2,KKOST                                         4940
         BT   ZSUB+12,*+20                                            4950
PN       NOP OUTC+1*2-2,05000,2                                       4960
         AM   PM+6,12                                                 4970
         AM   PN+6,12                                                 4980
         SM   PM+11,5                                                 4990
         AM   COUNT,1                                                 5000
         CM   COUNT,4                                                 5010
         BNE PM                                                       5020
*                 PUNCH TOTAL KKOSTS, TOTAL LLOAD, TOTAL              5021
*                 STUDENT MILES OR TIME AND THE ROUTE NUMBER          5022
         WACDOUTC,,,        FIFTH CARD PUNCHED                        5030
         WACDOUTT,,,               BLANK CARD PUNCHED                 5040
*                 IF CONSOLE SWITCH 2 IS NOT ON GO TO A800,           5041
*                 RESET THE COUNTERS AND GENERATE ANOTHER             5042
```

```
 *                  TABLE 6. CONTINUED
 *                 BUS ROUTE OTHERWISE GO TO A697                         5043
 A698  BC2 A697                                                           5050
       B   A800                                                           5060
 *                 IS THE NUMBER OF ROUTES CONSIDERED EQUAL               5061
 *                 TO OR LESS THAN THE PREVIOUSLY SET NUMBER              5062
 *                 IF NOT GO TO A800 AND RESET COUNTERS                   5063
 *                 OTHERWISE GO TO A508 AND PICK ANOTHER                  5064
 *                 STARTING POINT AND GENERATE ANOTHER ROUTE              5065
 A697  C   NRTC,NRC                                                       5070
       BP  A508                                                           5080
 A800  TFM NRC,0                                                          5090
       AM  KK,1                                                           5100
       BTM MULT,N                                                         5110
       AM  99,NSR                                                         5120
       TFM 99,0,67                                                        5130
       B   A908                                                           5140
 *     CONSTANTS USED IN PROGRAM                                          5150
 *                                                                        5160
 MLINK DSB 5,4000                                                         5170
 LMAT  DSB 5,4000                                                         5180
 KAP   DSB 5,20                                                           5190
 NSR   DSB 5,200                                                          5200
 MAT2  DSB 5,400                                                          5210
 MZ    DSB 5,60                                                           5220
 MILE  DSB 5,20                                                           5230
 KIDS  DSB 5,200                                                          5240
 MAT   DSB 5,400                                                          5250
 NX    DSB 5,200                                                          5260
 NP    DSB 5,200                                                          5270
 F12   DAS 1                                                              5280
```

* TABLE 6. CONTINUED

```
       DC   8,42646200
       DS   160
RD     DSS  81
N      DS   5
NLAR   DS   5
NOVER  DS   5
NBUS   DS   5
KIDST  DS   5
KK     DS   5
I      DS   5
NRC    DS   5
M      DS   5
J      DS   5
IA     DS   5
JA     DS   5
NST    DS   5
NRTC   DS   5
NPTU   DS   5
KOUNT  DS   5
II     DS   5
K      DS   5
F77    DAC  20,RENDO ERROR PHASE I-
       DS   142,*-1
LO     DS   5
L1     DS   5
KKS    DS   5
NPU    DS   5
LLOAD  DS   5
L      DS   5
LOAD   DS   5
```

TABLE 6. CONTINUED

```
*
KKOST DS  5
KOSTS DS  5
KOST  DS  5
MP    DS  5
MAX   DS  5
MIN   DS  5
MR    DS  5
KZ    DS  5
KX    DS  5
*     EXTRA CONSTANTS
TEMPI DS  5
TEMPM DS  5
SAVE  DS  5
ONE   DC  5,1
TWO   DC  5,2
THREE DC  5,3
OUT   DAS 80
OUTT  DAS 80
OUTA  DAS 80
OUTC  DAS 80
COUNT DC  5,0
NKID  DC  5,0
NKIDA DC  5,0
TAB   DSA KKOST,LLOAD,KKS,NRC
KTAB  DS  5
*     SUBROUTINES TO CALCULATE SUBSCRIPTS
      DS  5
MULT  MM  MULT-1,5,67
      SF  95
      SM  99,5
```

TABLE 6. CONTINUED

```
      BB                                        5900
      DS   10                                   5910
MT    MM   MT-1,5,610                           5920
      SF   95                                   5930
      TF   MTS,99                               5940
      MM   MT-6,100,69                          5950
      SF   95                                   5960
      A    99,MTS                               5970
      SM   99,105                               5980
      BB                                        5990
MTS   DS   5                                    6000
      DS   10                                   6010
MTT   MM   MTT-1,5,610                          6020
      SF   95                                   6030
      TF   MSTT,99                              6040
      MM   MTT-6,100,67                         6050
      SF   95                                   6060
      A    99,MSTT                              6070
      SM   99,105                               6080
      BB                                        6090
MSTT  DS   5                                    6100
      DS   10                                   6110
MTTS  MM   MTTS-1,5,610                         6120
      SF   95                                   6130
      TF   MTST,99                              6140
      MM   MTTS-6,100,69                        6150
      SF   95                                   6160
      A    99,MTST                              6170
      SM   99,105                               6180
      BB                                        6190
```

TABLE 6. CONTINUED

```
*
MTST  DS   5                                          6200
*     ZERO DELETION SUBROUTINE                        6210
ZSUB  NOP 0,0                                         6220
      SF   ZSUBA+6                                    6230
      SF   ZSUB+10                                    6240
ZSUBB BD   BBACK,ZSUB+9,11                            6250
ZSUBA TFM ZSUB+9,00,10                                6260
      AM   ZSUB+9,2                                   6270
      SM   ZSUB+11,1,10                               6280
      CM   ZSUB+11,0,10                               6290
      BNE ZSUBB                                       6300
BBACK BB                                              6310
*     START                                           6320
HTAA  DS   5                                          6330
S16   DC   5,16                                       6340
A5    DS   5                                          6350
HT    DS   5                                          6360
NTIME DS   5                                          6370
NT    DSB 5,400                                       6380
OUTR  DAS 80                                          6390
HTA   DS   10                                         6400
*     END                                             6410
ZEROX DC   60,0                                       6411
      DEND 402                                        6420
```

Note.---Below are the card sequence numbers, variables and their description for the above SPS Program.

90 N = Number of points in a school system, including the school.

100 NLAR = Number of levels or rows in the LMAT and [illegible] matrices, in other words, the maximum number of points that might

TABLE 6. CONTINUED

be visited from any given point.

110 NOVER = Number of students that may be loaded on a bus over the given capacity.

120 NBUS = Number of buses to be used in the system.

130 KIDST = Total number of students in a system.

140 HTAA = Temporary storage space for time units.

150 NTIME = School starting time expressed in hours and minutes, such as 0830.

200 HT = Time is converted to minutes and HT is storage area.

210 KK = Internal counter for identification of bus.

220 I = Internal counter for points.

260 KAP = Capacity of each bus.

270 MILE = Maximum time a bus may travel for a given number of pick up points. For any generated route whose bus distance is greater than MILE, the route is discarded.

380 NRC = Internal counter for number of routes generated.

390 M = Internal counter for number of pick up points excluding school, M + 1 = N.

430 KZ = Internal counter used with condensed matrix.

480 J = Level jth level. The jth level.

730 IA,JA = Coordinates in the (N,NLAR) matrix.

760 LMAT = A two dimensional matrix that describes the points that may be visited next from a given point. The numbers in any given column beginning in the second row from the top gives a list of the points. For example, the following information is the segment of the INPUT MATRIX listing Pick Up Point Number 4 (same data appears in both Figure 3 and Table 1).

TABLE 6. CONTINUED

NLAR	POINT	LMAT	MLINK*
1	4		
2	4	3	1
3	4	7	3
4	4	8	3
5	4	10	4
6	4	43	5
7	4	44	7
8	4	46	19
9	4		
	...		
15	4		19

(*Not used with LMAT)
Column NLAR lists the levels.
Column POINT indicates point number 4.
Column LMAT indicates that from Point Number 4, a bus may travel to points 3, 7, 8, 10, 43, 44 and 46 (46 being the school). In other words, from Point Number 4 a bus may go to six other points to pick up students or go to school.
The first element in Column LMAT, level ONE has a special function of assigning the level for starting the search for the next point to visit from a given point.

TABLE 6. CONTINUED

---

770 MLINK = a two dimensional matrix that gives the mileages or time from a given point to another given point. Consider the following array which was discussed above:

NLAR	POINT	LMAT	MLINK
1	4		
2	4	3	1
3	4	7	3
4	4	8	3
5	4	10	4
6	4	43	5
7	4	44	7
8	4	46	19
9	4		
	...		
15	4		19

Column NLAR lists the levels.
Column POINT indicates point number 4.
Column LMAT not used in MLINK.
Column MLINK gives the number of time units required to travel between Point Number 4 and a given point identified by LMAT(I,1). In the discussion of LMAT above, it stated that a bus could go from Point Number 4 to Point Number 10. By using the MLINK matrix, the distance between these two points is 4 units. Thus, LMAT (4,5) identifies travel to Point 10 and MLINK (4,5) gives time units as the travel time between Point Number 4 and Point Number 10. Since the first element (level ONE) in each column of LMAT does not describe a point, then the corresponding element in MLINK can be set to zero.

TABLE 6. CONTINUED

To indicate a route from Point Number 4 to Point Number 10, the number 5 would appear in level ONE:

NLAR	POINT	LMAT	MLINK
1	4	5	
2	4	3	1
3	4	7	3
4	4	8	3
5	4	10	4
6	4	43	5
7	4	44	7
8	4	46	19
9	4		
		...	
15	4		19

By changing the value of level ONE, LMAT, different routes can be generated. Initially LMAT (I,1) is set to 2 so that all feasible points from Point Number 4 can be considered. The first zero element in LMAT Column will cause the program to look for another route since all possible points have been exhausted. First zero element is at level NINE; therefore, the numbers of levels for any column should be one greater than the maximum number of points to be considered. In the present program, 15 levels were used (NLAR).

TABLE 6. CONTINUED

			In order to permit the program to terminate generation at any point, the last element in each column of MLINK should be the **time** from that point to school.
1050	NST	=	Level identification for the beginning of a route.
1060	NRTC	=	Maximum number of routes to be generated for any set of data. This value was introduced so that if after a relatively long period all the possible routes had not been generated, the computer would move on to the next set of data.
1070	NPTU	=	Number of pick up points to be used to generate bus routes.
1200	NX	=	List in memory containing the route as it is generated.
1210	NP	=	A true or false variable indicating if a point is to be considered as a possible pick up point for the present bus.
1220	KIDS	=	Number of children.
1240	NSR	=	List of points at which a school bus route may start.
1400	KOUNT	=	Internal counter for the number of points the present bus has visited.
1500	MT	=	Internal counter for subscript for matrices.
1510	ONE	=	See LMAT, line 760.
1530	K	=	Internal counter locates j level in LMAT matrix.
2280	MATZ	=	Storage for the pick up points for each route.
2330	NT	=	Internal counter to zero output areas MAT and MATZ.
2370	MAT	=	Storage for route prior to output time.
480	KKS	=	Total number of student time units in school system.

TABLE 6. CONTINUED

2490 KKOST = Total number of bus time units in school system.

2500 LLOAD = Number of students on all buses.

2520 KTAB = Used to eliminate "check stop" condition when all students can be transported on fewer buses than originally planned.

2580 MAX = Maximum load that can be assigned.

2590 MIN = Minimum load that can be assigned.

2610 LOAD = Number of students now on a bus.

2620 KOSTS = Number of student time units for a given bus for a given route.

2630 KOST = Number of time units for a given bus for a given route.

2640 LO = Number of students at a given bus stop that cannot be loaded on present bus. Might be thought of as excess students.

2720 MR = Internal counter.

2770 SAVE = Save for subsequent operations.

2790 L = Internal counter. MATZ (L,KK) variable subscript.

3720 MZ = Internal counter.

OUTPUT OF THE SPS PROGRAM

There are two different kinds of OUTPUT from the SPS School Bus Program. One kind of OUTPUT partitions a suggested route into individual bus routes, and a second generates routes. The remainder of this report is a detailed discussion of these two OUTPUTS.

Partitioning of the suggested route

Attention is directed to Suggested Route Number 1 which was presented graphically in Figure 4 and Table 2 and included the header card and data. Also needed for the partitioning are a list of buses to be used and a header card for the SPS Program. These data are fed into the computer in the following manner.

Suggested Route Partitioning Procedure, Phase 1

1620 Console switches (1, 2, 3, &4) OFF

Place SPS SCHOOL BUS PROGRAM in READ HOPPER of 1622

Press RESET 1620

Press LOAD 1622

Press READER START 1622 to read last card

SWITCH 4 1620 Console ON

Place HEADER CARD NUMBER 1 followed by deck of cards with the capacity of each bus to be used in READ HOPPER 1622

Press READER START 1622

Press READER START 1622 to read last card

Place CONDENSED MATRIX in READ HOPPER 1622

Press READER START 1622

Press READER START 1622 to read last card

SWITCH 4 1620 Console OFF

Place HEADER CARD 2 followed by suggested route in READ HOPPER of 1622

Press READER START 1622

Press READER START 1622 to read last card

Press PUNCH START 1622

Press NON PROCESS RUNOUT 1622 to secure complete output

The OUTPUT of the SPS School Bus Program using suggested route data will be presented in Tables 7, 8 and 9. (These tables are photographs of the computer output). In each case, the same suggested route was used (Suggested Route Number 1), and only the sizes and overload features of the buses were varied. To make these data more readily comprehensible descriptive information has been made on Table 7. Note should be made that the only purpose of this output is to partition Suggested Route 1 into individual bus routes; therefore, no interpretation is to be made. Tables 8 and 9 have been included to illustrate output variations as being dependent upon bus size (KAP) and overload values (NOVER).

TABLE 7. OUTPUT OF SUGGESTED ROUTE 1 WITH BUS CAPACITY OF 54 AND OVERLOAD OF 0

```
BUS       1
   7   19    7    7   14
  12   13   11    6    5                                    1339    54    28
 802  803  805  807  809

BUS       2
  16   12    2   11   13
   1    2    3    4    7                                    1267    54    27
 803  805  807  808  811

BUS       3
   2    8    8   24   10    2
   7    9    8   10   44   43                               1004    54    22
 808  809  810  811  815  817

BUS       4
  14    1   17   20    2
  43   45   41   40   42                                     965    54    22
 808  810  813  814  816

BUS       5
  20    5   26    3
  42   39   34   33                                         1034    54    21
 809  811  812  813

BUS       6
   9    6    2    7    9   14    7
  33   32   30   29   28   27   25                          1452    54    37
 753  754  757  759  807  809  813

BUS       7
   2   13   27   12
  25   24   23   22                                          871    54    19
 811  813  814  815

BUS       8
  21    7    4    9   10    3
  22   26   31   38   36   37                                 963    54    22
 808  810  812  816  817  819

BUS       9
  13   22    8   11
  37   35   19   20                                          774    54    16
 814  815  817  818

BUS      10
   1   12   21   18    2
  20   21   16   17   18                                     691    54    19
 811  813  818  819  821

BUS      11
  30    3    2
  18   14   15                                              1011    35    30
 800  805  812

 263   575 11371      1
```

Indicates 14 students at

Pick up Point #5

Bus is to arrive at Point #5 at 8:09 in order to arrive at school at 8:30

Bus #1 is to start route at Point #12 at 8:02

Total number of student time units for Bus #3

Number of students on Bus #3

Length of Bus Route #3 expressed in time units

Total time for all buses

Total number of students being transported

Total number of time units students spend enroute

Number of generation

TABLE 8. OUTPUT OF SUGGESTED ROUTE 1 WITH BUS CAPACITY OF 54 AND OVERLOAD OF 5

```
BUS        1
   7  19   7   7  14
  12  13  11   6   5
 802 803 805 807 809                                                    1339    54    28

BUS        2
  16  12   2  11  15
   1   2   3   4   7
 803 805 807 808 811                                                    1305    56    27

BUS        3
   8   8  24  10   9
   9   8  10  44  43
 809 810 811 815 817                                                    1051    59    21

BUS        4
   7   1  17  20  14
  43  45  41  40  42
 808 810 813 814 816                                                     979    59    22

BUS        5
   8   5  26  12   6
  42  39  34  33  32
 808 810 811 812 813                                                    1088    57    22

BUS        6
   2   7   9  14   9  13
  30  29  28  27  25  24
 755 757 805 807 811 813                                                1240    54    35

BUS        7
  27  32
  23  22
 814 815                                                                 912    59    16

BUS        8
   1   7   4   9  10  16  12
  22  26  31  38  36  37  35
 806 808 810 814 815 817 818                                             904    59    24

BUS        9
  10   8  12  12  17
  35  19  20  21  16
 808 810 811 813 818                                                    1016    59    22

BUS       10
   4  18  32
  16  17  18
 818 819 821                                                             534    54    12

BUS       11
   3   2
  14  15
 805 812                                                                 111     5    25

  254    575 10479       1
```

TABLE 9. OUTPUT OF SUGGESTED ROUTE 1 WITH BUS CAPACITY OF 60 AND OVERLOAD OF 5

```
BUS       1
   7  19   7   7  14  11
  12  13  11   6   5   1                                               1743    65    31
 759 800 802 804 806 808

BUS       2
   5  12   2  11  15   8   8
   1   2   3   4   7   9   8                                           1410    61    29
 801 803 805 806 809 810 811

BUS       3
  24  10  16   1  14
  10  44  43  45  41                                                   1197    65    23
 807 811 813 815 818

BUS       4
   3  20  22   5  15
  41  40  42  39  34                                                   1229    65    22
 808 809 811 813 814

BUS       5
  11  12   6   2   7   9  14
  34  33  32  30  29  28  27                                           1740    61    36
 754 755 756 759 801 809 811

BUS       6
   9  13  27  16
  25  24  23  22                                                       1064    65    19
 811 813 814 815

BUS       7
  17   7   4   9  10  16
  22  26  31  38  36  37                                               1018    63    22
 808 810 812 816 817 819

BUS       8
  22   8  12  12  11
  35  19  20  21  16                                                   1208    65    22
 808 810 811 813 818

BUS       9
  10  18  32
  16  17  18                                                            606    60    12
 818 819 821

BUS      10
   3   2
  14  15                                                                111     5    25
 805 812

  241    575 11326      1
```

Generating Routes

After the suggested route has been partitioned, individual bus routes are simulated so that the best route can be identified. This operation is called Phase 2.

PHASE 2

The INPUT data for Phase 2 consists of the following:

Header cards for supplementary data for each bus

Supplementary data for each bus

List of buses, capacity of each and upper cost limits

Header card for SPS School Bus Program

To prepare the data for Phase 2 the initial step is to examine the OUTPUT of the SPS School Bus Program in Phase 1, which is based on each suggested route data. Table 10 illustrates the type of examination and alterations that are to be performed and is actually a work copy of the same data presented as Table 7.

The first change that occurs is in case of Buses 2 and 3 involving bus stop Number 7. At Pick-up Point Number 7, thirteen students are assigned to Bus 2; and also two students are assigned to Bus 3. Since there are only 54 children on Bus 2, the decision is made not to split Pick-up Point Number 7 between the two buses. Therefore, the following four changes are made:

1. Put all 15 students at Point 7 on Bus 2.
2. Increase load from 54 to read 56.
3. Mark off Point 7 in case of Bus 3.
4. Decrease the load of Bus 3 by 2 students.

The second change that is made is in case of Buses 3 and 4. In this instance the students at Pick-up Point Number 43 are split between Buses 3 and 4. An inspection of the map (See Figure 4) suggests that there is no preference as to which bus the students should ride; and perhaps better routes would result if the students were not divided between buses. Therefore, it was decided to load all 16 students at Point 43 on Bus 4. The following four changes were made:

1. Put all 16 students at Point 43 on Bus 4.
2. Increase load of Bus 4 to reflect change.
3. Mark off Point 43 in case of Bus 3.
4. Decrease load of Bus 3 to reflect change.

The other changes that appear in Table 10 are made in the same manner. When these changes are completed, the largest load will be Bus 7 with 61 students; and the smallest load will be 37 students on Bus 11.

Certain criticisms may be directed toward the poorly defined method of making the changes listed above. However, if one uses a map while making these changes, these criticisms should tend to cease or to be of any great concern after experience is gained.

TABLE 10. CHANGES IN PARTITIONING OF SCHOOL BUS ROUTES FOR SUGGESTED ROUTE 1
WITH BUS CAPACITY OF 54 AND OVERLOAD OF 0

BUS 1
7 19 7 7 14
12 13 11 6 5 CK 1339 54 28
802 803 805 807 809

BUS 2
16 12 2 11 ~~13~~ 15
1 2 3 4 7 1267 ~~54~~ 56 27
803 805 807 808 811

BUS 3
~~2~~ 8 8 24 10 ~~2~~
~~7~~ 9 8 10 44 ~~45~~ 1004 ~~54~~ 50 22
808 809 810 811 815 817

BUS 4
~~14~~ 16 1 17 20 ~~2~~
43 45 41 40 ~~42~~ 965 54 22
808 810 813 814 816

BUS 5
~~20~~ 22 5 26 3
42 39 34 33 1034 ~~54~~ 56 21
809 811 812 813

BUS 6
9 6 2 7 9 14 ~~7~~
33 32 30 29 28 27 ~~25~~ 1452 ~~54~~ 47 37
753 754 757 759 807 809 813

BUS 7
~~2~~ 9 13 27 12
25 24 23 22 871 ~~54~~ 61 19
811 813 814 815

BUS 8
21 7 4 9 10 3
22 26 31 38 36 37 CK 963 54 22
808 810 812 816 817 819

BUS 9
13 22 8 ~~11~~ 12
37 35 19 20 774 ~~54~~ 55 16
814 815 817 818

BUS 10
~~1~~ 12 21 18 ~~2~~
~~20~~ 21 16 17 ~~18~~ 691 ~~54~~ 51 19
811 813 818 819 821

BUS 11
~~30~~ 32 3 2
18 14 15 1011 ~~35~~ 37 30
800 805 812

263 575 11371 1

After the above changes have been made in the output for each suggested route, a new set of bus capacities and time limits have been determined. Table 11 lists these values based upon the changes recorded in Table 10. In the case of Bus Number 1, the capacity will be 54 children; and only routes being equal to or less than 28 time units are to be punched. (All routes will be generated and numbered; but only those routes meeting the cost limits, cost being expressed in time units, will be punched). Bus Number 2 will have a load of 56 students with an upper limit of 27 time units. Data for the remainder of the buses is treated in the same manner.

Upon completing this step, data is available for the preparation of the Supplementary Data Header Card 2 (same as described in Phase 1). Attention is directed to Table 12. The first row of numbers in Table 12 lists the values for the HEADER CARD 2 for Bus Number 1:

46 indicates the number of points in the system.

01 indicates one bus is to be used.

05 indicates to the computer the point at which the starting point will be found (to be taken literally).

200 indicates the number of generations to be made. This value is included to have some means to keep the computer from going on and on.

05 indicates the number of pick-up points to be assigned to the first bus.

Below the header card data in Table 12 the following five items of information appear: listing of the 46 points; identification of the points to be included on the bus route; the number of children at each point; the level values necessary for the generation procedures; and the list of reasonable starting points for that particular bus. These values are determined from a study of data given in Table 10 and a map of the suggested route, Figure 4.

TABLE 11. CAPACITY AND UPPER LIMITS OF THE COST (TIME) FOR EACH OF THE 11 BUSES WHICH WILL BE USED IN SUPPLEMENTARY DATA AND BASED ON DATA FOUND IN TABLE 10

CAPACITY	LIMIT
54	28
56	27
50	22
54	22
56	21
47	37
61	19
54	22
55	16
51	19
37	30

TABLE 12. HEADER CARD 2 AND SUPPLEMENTARY DATA FOR EACH OF THE 11 SCHOOL BUSES GIVEN IN TABLE 11

```
46   01   05  200   05     ( Bus #1 )


01
02
03
04
05   01   14   02   05
06   01   07   02   06
07   00   00   02   11
08   00   00   02   12
09   00   00   02   13
10
11   01   07   02   00
12   01   07   02   00
13   01   19   02   00
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
```

TABLE 12. CONTINUED

46	01	01	200	05	(Bus # 2)
01	01	16	02	01	
02	01	12	02	02	
03	01	02	02	07	
04	01	11	02	00	
05					
06					
07	01	15	02	00	
08					
09					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					

TABLE 12. CONTINUED

```
46   01   08  200   04     ( Bus # 3 )

01
02
03
04
05
06
07
08   01   08   02   08
09   01   08   02   09
10   01   24   02   00
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44   01   10   02   00
45
```

TABLE 12. CONTINUED

46	01	40	200	04	(Bus # 4)
01					
02					
03					
04					
05					
06					
07					
08					
09					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40	01	20	02	40	
41	01	17	02	41	
42	00	00	02	43	
43	01	16	02	45	
44					
45	01	01	02	00	

TABLE 12. CONTINUED

46	01	33	200	04	(Bus # 5)
01					
02					
03					
04					
05					
06					
07					
08					
09					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33	01	03	02	33	
34	01	26	02	34	
35					
36					
37					
38					
39	01	05	02	00	
40					
41					
42	01	22	02	00	
43					
44					
45					

TABLE 12. CONTINUED

46	01	27	200	06	(Bus # 6)
01					
02					
03					
04					
05					
06					
07					
08					
09					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27	01	14	02	27	
28	01	09	02	28	
29	01	07	02	29	
30	01	02	02	30	
31					
32	01	06	02	00	
33	01	09	02	00	
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					

TABLE 12. CONTINUED

46 01 22 200 04 (Bus # 7)

01				
02				
03				
04				
05				
06				
07				
08				
09				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22	01	12	02	23
23	01	27	02	24
24	01	13	02	25
25	01	09	02	00
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37				
38				
39				
40				
41				
42				
43				
44				
45				

TABLE 12. CONTINUED

46	01	22	200	06	(Bus # 8)
01					
02					
03					
04					
05					
06					
07					
08					
09					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22	01	21	02	22	
23	00	00	02	26	
24					
25					
26	01	07	02	00	
27					
28					
29					
30					
31	01	04	02	00	
32					
33					
34					
35					
36	01	10	02	00	
37	01	03	02	00	
38	01	09	02	00	
39					
40					
41					
42					
43					
44					
45					

TABLE 12. CONTINUED

46	01	19	200	04	(Bus # 9)
01					
02					
03					
04					
05					
06					
07					
08					
09					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19	01	08	02	19	
20	01	12	02	20	
21	00	00	02	37	
22	00	00	02	35	
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35	01	22	02	00	
36					
37	01	13	02	00	
38					
39					
40					
41					
42					
43					
44					
45					

TABLE 12. CONTINUED

46	01	16	200	03	(Bus # 10)
01					
02					
03					
04					
05					
06					
07					
08					
09					
10					
11					
12					
13					
14					
15					
16	01	21	02	16	
17	01	18	02	17	
18	00	00	02	21	
19					
20					
21	01	12	02	00	
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					

TABLE 12. CONTINUED

46	01	14	200	03	(Bus # 11)
01					
02					
03					
04					
05					
06					
07					
08					
09					
10					
11					
12					
13					
14	01	03	02	15	
15	01	02	02	00	
16					
17					
18	01	32	02	00	
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					

From Table 10 you are to note that Points 12, 13, 11, 6, and 5 are assigned to Bus 1. Since Point 5 is the lowest numbered point, Table 12 values will start at that place. (The format of Table 12 may appear to be awkward. However, any corrections can be readily made; then by gang punching decks of cards, not much time is actually involved). Reading row 05 in Table 12:

05 indicates Point 5.

01 indicates that the point is to be included on the present route (00 would have indicated that the point was not to be used).

14 indicates 14 students are at Pick-up Point 5.

02 indicates the level value for the computer to start generating.

05 indicates that the first starting point to be considered is Point 5. Any one of the five points to be included for Bus 1 could appear in this position.

In summary the second column of Table 12, an 01 is found for all points to be used for the school bus in question, namely 5, 6, 11, 12 and 13. For each of these points the number of children at each point appears in the third column. In the fourth column 02 indicates the initial level for the generation phase. In the fifth column, appearing in order from low to high, are the points that are assumed to be reasonable starting points for that bus. All five points appear to be reasonably good starting points in the case of Bus 1.

Attention is now directed to the second page of Table 12 which presents the data for Bus 2. The header card data will not be discussed. In the fifth column you note that only three starting points are being considered (1, 2 and 7) and five points (1, 2, 3, 4 and 7) are to be included on the route. By marking on Figure 4 these latter five points, it is hoped that the reader will agree that it would be unlikely for a bus to begin a route at eigher Points 3 or 4. However, should there be any doubt about suggesting starting points, these points should be included, because the computer certainly can generate and evaluate routes faster than the time one can spend wondering if such a starting point should be included.

The remainder of Table 12 is prepared in like manner. One note of caution is needed. These data presented herein are for a relatively densely populated area; and thus buses can be loaded in a very few stops; therefore, the number of starting points will be few. When one considers that the theoretical total number of school bus routes can be N!, and if each point is also indicated as a starting point, and if the maximum number of points that can be considered for each bus is 12 (the program is being changed to allow 20 points), then the number of possible starting points must be held to a minimum if a solution is to be achieved. For this reason, the present SPS School Bus Program will be far more efficient for heavily populated areas than for rural areas.

All data have now been prepared for Phase 2. These data are fed into the computer in the manner given below. The same Header Card 1 is being used as was given in Phase 1.

Generation Procedures, Phase 2

SWITCH 1 OFF

2 ON (To generate all routes).

3 OFF

4 OFF

Place School Bus SPS Program in READ HOPPER 1622

Press LOAD 1622

Press READER START 1622 to read in last card.

SWITCH 1 OFF

2 ON

3 OFF

4 ON (To read in matrix).

Place HEADER CARD NO. 1 in READ HOPPER 1622, followed by individual card for each bus which shows capacity and maximum cost for each bus (Cost may be expressed in minutes).

Press READER START 1622

Press READER START 1622 to read in last card.

Place Condensed Matrix in READ HOPPER 1622

Press READER START 1622

Press READER START 1622 to read in last card.

SWITCH 1 OFF

2 ON

3 OFF

4 OFF

Place HEADER CARD NO. 2 for Bus 1 followed by supplementary deck for Bus 1, followed by HEADER CARD NO. 2 for Bus 2. Supplementary Deck for Bus 2, followed by HEADER CARD NO. 2 and Supplementary Deck for Bus 3--- for N buses in READ HOPPER 1622

Press READER START 1622

Press PUNCH START 1622

Press READER START 1622 to read in last card for N bus

The OUTPUT of the SPS School Bus Program using the Supplementary Data (given in Table 12) is presented in Table 13 with a total computer operation time of approximately eight minutes. The format of the OUTPUT is the same as in Table 7. Therefore, in the first generated route for Bus 1 the bus will start at 8:02 at Point 5, pick up 14 children; then proceed to Point 6, arriving at 8:04, pick up 7 children and will continue in a like manner until all points are used. Summary data for the first generated route appear in two places--immediately below the route followed by a 1 (indicating the first generated route) and on the extreme right-hand side of the page. In other words, the total student time cost for the route is 1321 student time units. These 54 students are being transported in 28 bus time units.

After inspection of the 14 actual routes punched for Bus 1, the third output (named generation 6) is considered to be the best route because it yields 1237 student time units, 54 students and 25 bus time units. Furthermore, generations 2, 3, 5, 8, 10 and 18 were not punched because their bus time unit values were greater than the limit of 28 (see limits mentioned in Table 11).

Only three outputs were punched for Bus 2 in Table 13; although at least 10 were generated. The third generation is considered the best solution.

An interesting situation arises in regard to Bus 4. Both generations 3 and 9 have 17 bus time units--the shortest of the 12 generated routes for Bus 4. On the other hand, generation 12 yields the fewest student units--738 compared to 823 and 751 for generations 3 and 9 respectively. Since we are transporting students rather than driving buses, generation 12 is considered to be the best; although it is not the shortest. These data suggest that the shortest bus miles criteria may not be a good criteria for evaluating school bus routes.

After identifying the best routes for each bus, a graphic representation of these routes is given in Figure 7 and a statistical summary in Table 14.

From Figure 7 it may be seen:

Route 1 starts at Point 5 to 11, 12, 13, 6 and to school

Route 2 starts at Point 1 to 2, 7, 3, 4 and to school

Route 3 starts at Point 9 to 8, 10, 44 and to school

Route 4 starts at Point 45 to 43, 40, 41 and to school

Route 5 starts at Point 33 to 34, 39, 42 and to school

Route 6 starts at Point 28 to 27, 30, 29, 32, 33 and to school

TABLE 13. OUTPUT OF SUPPLEMENTARY DATA FOR SOLUTION 1

```
BUS         1
  14   7   7   7  19
   5   6  11  12  13                                              1321    54    28
 802 804 806 807 808
  28      54  1321       1

BUS         1
  14   7  19   7   7
   5   6  13  12  11                                              1345    54    28
 802 804 806 807 808
  28      54  1345       4

BUS         1
  14   7   7  19   7
   5  11  12  13   6                                              1237    54    25
 805 806 807 808 810
  25      54  1237       6

BUS         1
   7  14   7   7  19
   6   5  11  12  13                                              1286    54    27
 803 805 806 807 808
  27      54  1286       7

BUS         1
   7  19   7   7  14
   6  13  12  11   5                                              1247    54    26
 804 806 807 808 809
  26      54  1247       9

BUS         1
   7   7  19   7  14
  11  12  13   6   5                                              1301    54    27
 803 804 805 807 809
  27      54  1301      11

BUS         1
   7   7  14   7  19
  12  11   5   6  13                                              1335    54    28
 802 803 804 806 808
  28      54  1335      12

BUS         1
   7   7  19   7  14
  12  11  13   6   5                                              1315    54    28
 802 803 805 807 809
  28      54  1315      13

BUS         1
   7  19   7  14   7
  12  13   6   5  11                                              1360    54    28
 802 803 805 807 808
  28      54  1360      14
```

TABLE 13. CONTINUED

```
BUS        1
   7  19   7   7  14
  12  13   6  11   5                                             1299    54    27
 803 804 806 808 809
   27      54  1299      15

BUS        1
   7  19   7  14   7
  12  13  11   5   6                                             1266    54    26
 804 805 807 808 810
   26      54  1266      16

BUS        1
   7  19   7   7  14
  12  13  11   6   5                                             1339    54    28
 802 803 805 807 809
   28      54  1339      17

BUS        1
  19   7   7  14   7
  13  12  11   5   6                                             1252    54    25
 805 806 807 808 810
   25      54  1252      19

BUS        1
  19   7   7   7  14
  13  12  11   6   5                                             1325    54    27
 803 804 805 807 809
   27      54  1325      20
```

TABLE 13. CONTINUED

```
BUS        2
  16  12   2  11  15
   1   2   3   4   7                                          1305     56     27
 803 805 807 808 811
   27     56  1305       1

BUS        2
  16  12  15   2  11
   1   2   7   3   4                                          1283     56     26
 804 806 808 810 811
   26     56  1283       3

BUS        2
  15  12  16   2  11
   7   2   1   3   4                                          1322     56     27
 803 805 807 810 811
   27     56  1322      10




BUS        3
   8   8  24  10
   9   8  10  44                                               834     50     19
 811 812 813 817
   19     50   834       1
```

TABLE 13. CONTINUED

```
BUS        4
  20  17   1  16
  40  41  45  43                                                        909   54   19
 811 812 815 817
   19      54   909       1

BUS        4
  20  16   1  17
  40  43  45  41                                                        891   54   20
 810 813 815 818
   20      54   891       2

BUS        4
  17  20  16   1
  41  40  43  45                                                        828   54   17
 813 814 817 819
   17      54   828       3

BUS        4
  17  20   1  16
  41  40  45  43                                                        869   54   18
 812 813 815 817
   18      54   869       4

BUS        4
  17   1  20  16
  41  45  40  43                                                        903   54   21
 809 812 814 817
   21      54   903       5

BUS        4
  17   1  16  20
  41  45  43  40                                                        891   54   21
 809 812 814 817
   21      54   891       6

BUS        4
  16  20  17   1
  43  40  41  45                                                        837   54   18
 812 815 816 819
   18      54   837       7

BUS        4
  16  20   1  17
  43  40  45  41                                                        879   54   20
 810 813 815 818
   20      54   879       8

BUS        4
  16   1  20  17
  43  45  40  41                                                        751   54   17
 813 815 817 818
   17      54   751       9
```

TABLE 13. CONTINUED

```
BUS      4
  16   1  17  20
  43  45  41  40                                                    819  54   19
 811 813 816 817
   19    54   819     10

BUS      4
   1  17  20  16
  45  41  40  43                                                    837  54   20
 810 813 814 817
   20    54   837     11

BUS      4
   1  16  20  17
  45  43  40  41                                                    738  54   18
 812 814 817 818
   18    54   738     12
```

TABLE 13. CONTINUED

```
BUS      5
   3  26   5  22
  33  34  39  42                                                   884    56    18
 812 813 814 816
   18     56    884     1

BUS      5
   3  22   5  26
  33  42  39  34                                                   982    56    21
 809 811 813 814
   21     56    982     2

BUS      5
  26   3   5  22
  34  33  39  42                                                   936    56    19
 811 812 814 816
   19     56    936     3

BUS      5
  26   3  22   5
  34  33  42  39                                                   970    56    19
 811 812 814 816
   19     56    970     4

BUS      5
  26   5   3  22
  34  39  33  42                                                   940    56    19
 811 812 814 816
   19     56    940     5
```

TABLE 13. CONTINUED

```
BUS        6
  14   9   7   2   6   9
  27  28  29  30  32  33                                                     1173    47    32
 758 800 808 810 812 813
  32      47 1173      1

BUS        6
  14   2   9   7   6   9
  27  30  28  29  32  33                                                     1225    47    35
 755 757 801 809 812 813
  35      47 1225      2

BUS        6
   9  14   2   7   6   9
  28  27  30  29  32  33                                                     1047    47    27
 803 805 807 809 812 813
  27      47 1047      3

BUS        6
   9   7   2  14   6   9
  28  29  30  27  32  33                                                     1105    47    34
 756 804 806 808 812 813
  34      47 1105      4

BUS        6
   7   9  14   2   6   9
  29  28  27  30  32  33                                                     1049    47    32
 758 806 808 810 812 813
  32      47 1049      5

BUS        6
   7   2   9  14   6   9
  29  30  28  27  32  33                                                     1051    47    30
 800 802 806 808 812 813
  30      47 1051      6

BUS        6
   2  14   9   7   6   9
  30  27  28  29  32  33                                                     1169    47    33
 757 759 801 809 812 813
  33      47 1169      7

BUS        6
   2   7   9  14   6   9
  30  29  28  27  32  33                                                     1077    47    34
 756 758 806 808 812 813
  34      47 1077      8
```

TABLE 13. CONTINUED

```
BUS       7
    9  13  27  12
   25  24  23  22                                                           1004    61    19
  811 813 814 815
    19      61  1004      2



BUS       8
   21   7   4   9  10   3
   22  26  31  38  36  37                                                    963    54    22
  808 810 812 816 817 819
    22      54    963      1
```

TABLE 13. CONTINUED

```
BUS       9
   8  12  22  13
  19  20  35  37
 815 816 818 819                                                          695    55    15
   15     55    695      1

BUS       9
  12   8  22  13
  20  19  35  37
 815 816 818 819                                                          699    55    15
   15     55    699      3

BUS       9
  12   8  13  22
  20  19  37  35
 814 815 817 818                                                          745    55    16
   16     55    745      4

BUS       9
  12  22  13   8
  20  35  37  19
 814 816 817 819                                                          757    55    16
   16     55    757      6

BUS       9
  13  22   8  12
  37  35  19  20
 814 815 817 818                                                          786    55    16
   16     55    786      9

BUS       9
  13  22  12   8
  37  35  20  19
 815 816 818 819                                                          735    55    15
   15     55    735     10

BUS       9
  22  12   8  13
  35  20  19  37
 814 816 817 819                                                          767    55    16
   16     55    767     11

BUS       9
  22  13   8  12
  35  37  19  20
 814 815 817 818                                                          795    55    16
   16     55    795     12
```

TABLE 13. CONTINUED

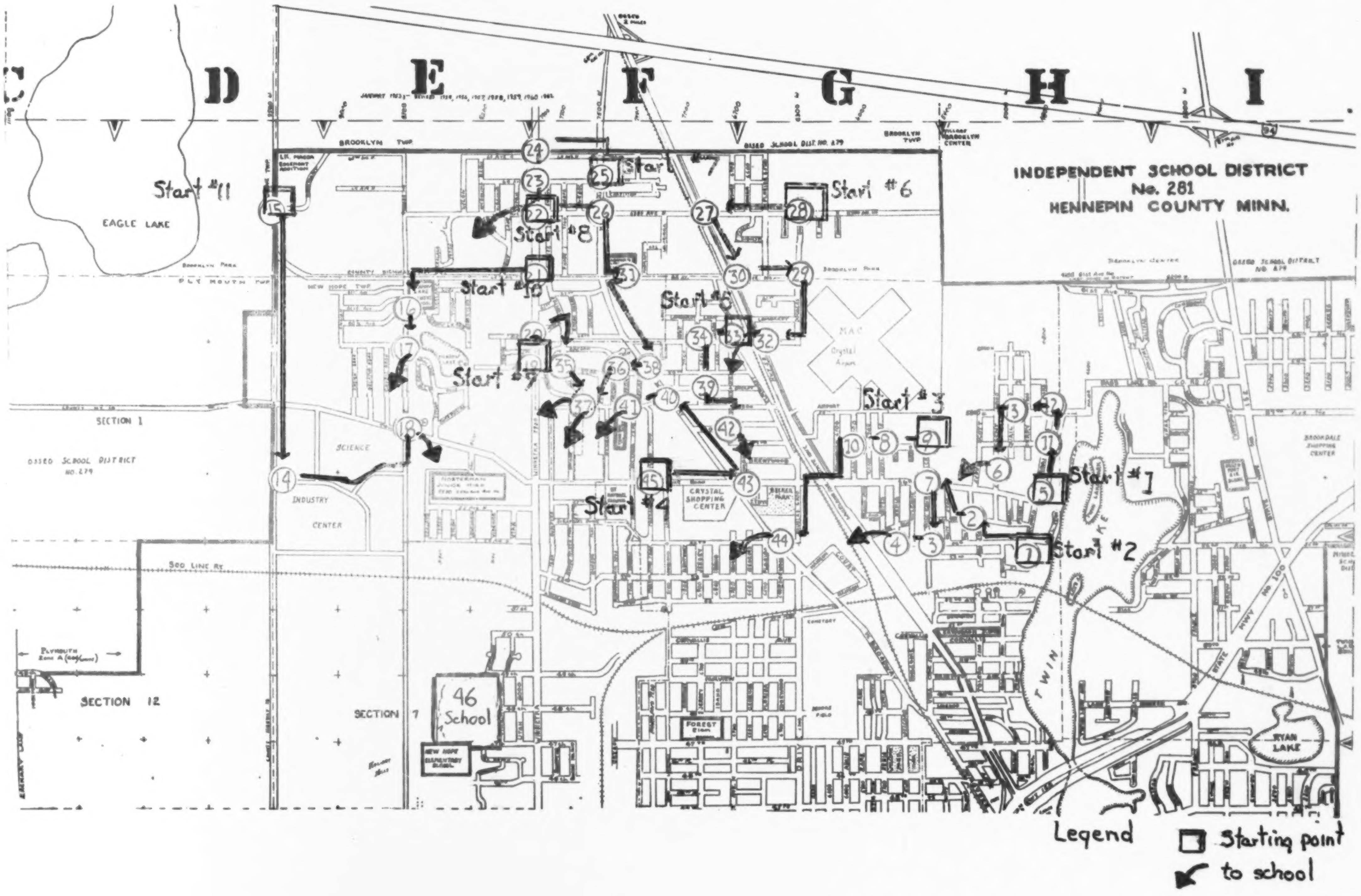
```
BUS      10
  18  21  12
  17  16  21                                                       876    51    19
 811 812 817
   19     51    876       1

BUS      10
  12  21  18
  21  16  17                                                       654    51    17
 813 818 819
   17     51    654       2



BUS      11
   2   3  32
  15  14  18                                                       372    37    21
 809 816 821
   21     37    372       1

BUS      11
   2  32   3
  15  18  14                                                       593    37    24
 806 814 819
   24     37    593       2
```



INDEPENDENT SCHOOL DISTRICT
No. 281
HENNEPIN COUNTY MINN.
C
D
E
F
G
H
I
Start #1
Start #2
Start #3
Start #4
Start #5
Start #6
Start #7
Start #8
Start #9
Start #10
Start #11
46 School
EAGLE LAKE
SECTION 1
SECTION 7
SECTION 12
OSSEO SCHOOL DISTRICT NO. 279
BROOKLYN TWP
BROOKLYN PARK
PLYMOUTH TWP
NEW HOPE TWP
SCIENCE
INDUSTRY
CENTER
CRYSTAL SHOPPING CENTER
MAC
Crystal Airport
SOO LINE RY.
TWIN LAKE
RYAN LAKE
BROOKDALE SHOPPING CENTER
FOREST ELEM.
NEW HOPE ELEMENTARY SCHOOL
Legend
Starting point
to school

Figure 7. Best school bus routes based upon Suggested Route Number 1.

TABLE 14. SUMMARY DATA FOR SOLUTION 1

BUS	GENERATION	STUDENT TIME	LOAD	BUS TIME
1	6	1237	54	25
2	3	1283	56	26
3	1	834	50	19
4	12	738	54	18
5	1	884	56	18
6	3	1047	47	27
7	2	1004	61	19
8	1	963	54	22
9	1	695	55	15
10	2	654	51	17
11	1	372	37	21
TOTAL		9711	575	227

Route 7 starts at Point 25 to 24, 23, 22 and to school

Route 8 starts at Point 22 to 26, 31, 38, 36, 37 and to school

Route 9 starts at Point 19 to 20, 35, 37 and to school

Route 10 starts at Point 21 to 16, 17 and to school

Route 11 starts at Point 15 to 14, 18 and to school

The application of the same procedures as have been demonstrated here in using Suggested Route 1 can be used for Suggested Routes 2 and 3 (see Figures 5 and 6). Summary data for all three suggested routes are present in Table 15. These data are presented for demonstrational purposes only and should not be interpreted as a suggestion that larger buses tend to be less efficient than smaller buses. In order to arrive at the best route system for any given school district, data comparable to that given in Table 15 would have to be prepared using at least three different suggested routes. The sizes of school buses would have to be considered in terms of transporting the largest number of pupils in shortest amount of time.

In the original proposal it was not foreseen that the bus route used to take children home would be greatly different from the one used to take the children to school. However, as the study progressed it became apparent that the reversal of the morning routes can only be used where there is no one way street, no turn restrictions and similar traffic features. Work is being done on the return routing system, and all interested persons should contact the Director for further developments.

TABLE 15. SUMMARY DATA FOR SUGGESTED ROUTES 1, 2 AND 3 (SEE FIGURES 4, 5 AND 6)

SOLUTION	NUMBER OF BUSES	RANGE OF BUS SIZE	STUDENT TIME	LOAD	BUS TIME
1	11	37-61	9711	575	227
2	11	35-63	9787	575	241
3	10	55-62	10611	575	236

SUMMARY

The purpose of this Final Report was to describe an algorithm that can be used to design school bus routes.

Some of the more general conclusions of this study are as follows:

1. A heuristic solution to the school bus routing problem seems to be a satisfactory one at this time. Mathematical solutions would be too expensive, if not impossible.

2. There are some indications that the greater the school population density, the more efficient the SPS School Bus Computer Program becomes.

3. The most troublesome problem with the computer program to design school bus routes is having all data correct at INPUT time. All work should be checked independently at least twice.

4. A field test of the computer program indicates that school bus routes can be designed that are as short or shorter than routes designed by hand. Therefore, the computer technique may offer a greater saving of time than financial savings for transportation directors.

5. Because the amount of computer time required to design routes will vary according to school district, no time estimates will be given. The longest time required to design the school bus system for any system to date has been one hour for pupils transported by buses in a rural community. In a heavily populated area, less than ten minutes were required to route 11 buses transporting approximately 600 students.

6. The present computer program is being revised constantly, and any person contemplating the use of it should contact the Director for the latest development. The three changes now in progress are:

   a. Using address or descriptive names to identify bus stops rather than the use of numbers.

   b. Increasing the maximum number of bus stops per bus from 12 to 20.

   c. Generating return routes as well as going to school routes. However, there is one practical problem that has to be dealt with--Does a child have to ride in the same bus both ways? In other words, can he ride in Bus 46 in the morning and 84 in the afternoon?

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